COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

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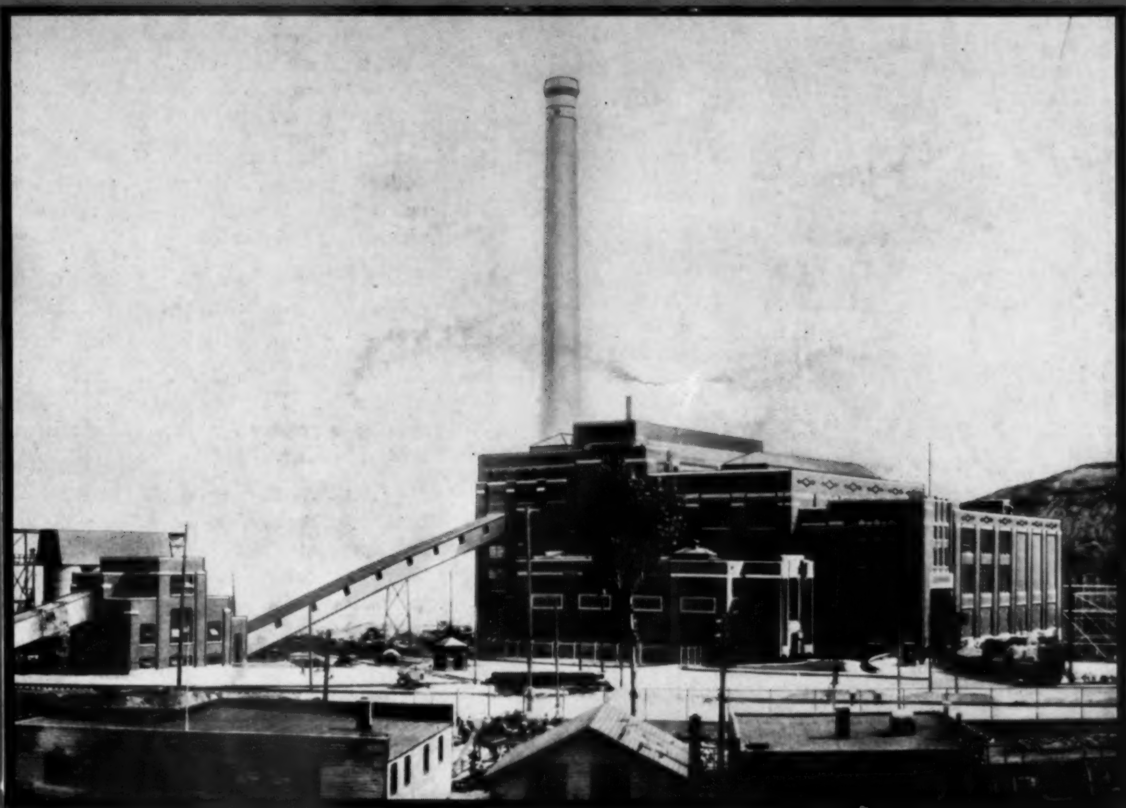


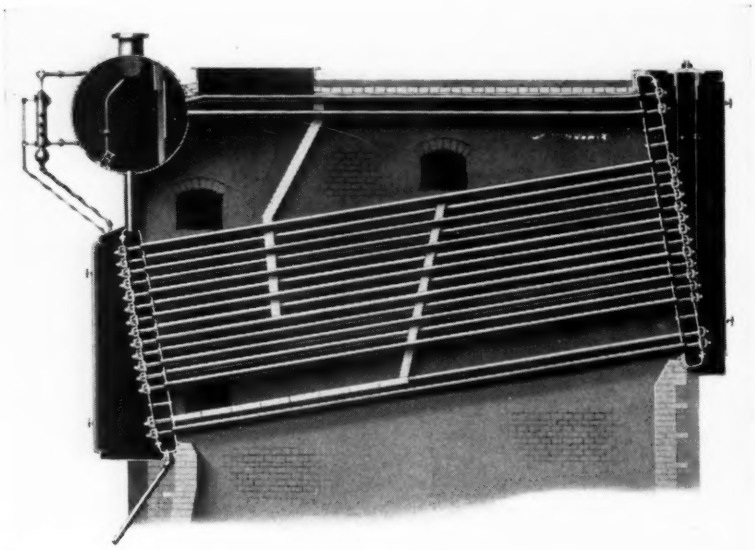
Port Washington Station of Milwaukee Electric Railway & Light Company, which recently went into service

A Control Chart for Interpretation of Coal Sampling Data

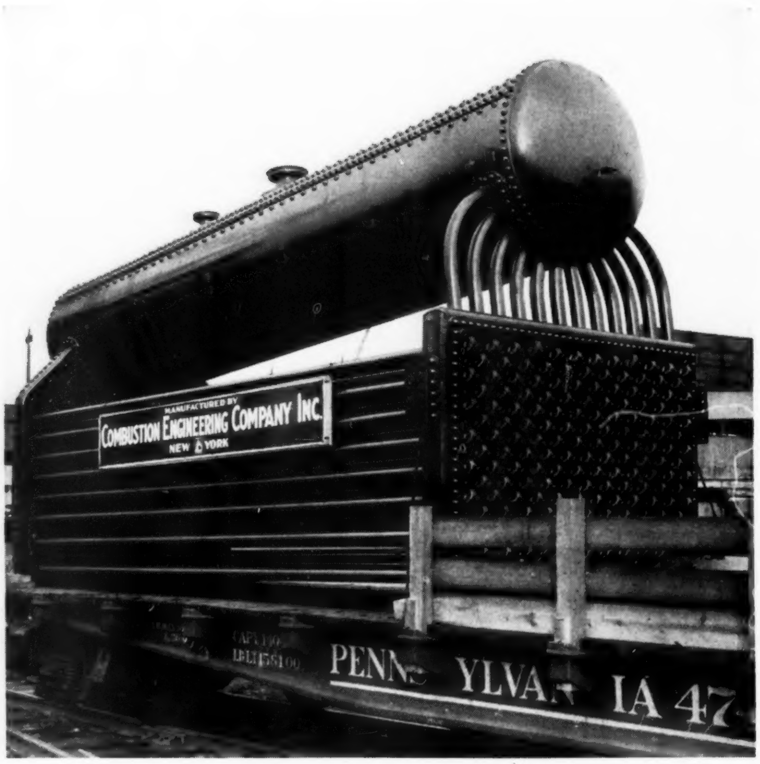
Cause and Prevention of Turbine-Blade Deposits

HEINE Box Header BOILERS

28,369,000 sq ft of Heating Surface Installed



Heine Cross Drum Boiler



Heine Long Drum Boiler on way to Loewers Gambrinus Brewery, New York

FEATURES

Headers . . . Single seam design eliminates end plates. Handhole sheet is attached to tube sheet by one row of rivets. The single caulking edge faces the outside, making inspection easy. No rivets in hot gas or fire zones. The tube sheet and handhole sheet are both made of firebox quality steel. Staybolts are screwed in, expanded and beaded. Supporting lugs are attached to the sides of the headers.

Drums . . . May be either fusion welded or riveted with single seam, double strap, butt joints. Firebox quality steel is used throughout. Perforated feed pipe, steam baffle and dry pipe are included.

Handholes and Fittings . . . Gasket surfaces around handhole openings and on handhole plates are machined.

Tubes . . . Made of steel tubing. All tubes interchangeable. Easy to inspect and clean. Tube spacing is greater for cross baffling than for longitudinal baffling.

Baffles . . . Refractory tile used for longitudinal baffling. Cross baffling, consisting of monolithic refractory material moulded while tubes are being inserted, assures tightness as well as providing for the removal of tubes without damage to the baffles.

General Design . . . The design, material and workmanship in this boiler are the best that modern engineering skill can produce. Within shipping clearances, boilers can be delivered completely assembled with baffles in place. When field assembly is necessary, no riveting or caulking is required. This type of boiler has wide application and is, in many cases, the most satisfactory type for plants where headroom is limited.

Steam Quality . . . At normal ratings, the moisture content in the steam will be less than 1 per cent.

For more than 50 years the name "Heine" has been the standard of comparison in the box header boiler field. Today thousands of Heine Boilers (10,482 have been sold to date) are giving dependable and economical service in every industry and every state in the Union. Heine Boilers are available in both cross drum and long drum types in sizes up to about 12,000 sq ft and for pressures up to approximately 300 lb. For such conditions you can buy Heine Boilers with assurance that you are getting the best value the market affords. . . Combustion Engineering Company, Inc., 200 Madison Avenue, New York.

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COMBUSTION ENGINEERING

COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

VOLUME SEVEN NUMBER SIX

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FOR DECEMBER 1935

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WHAT IS BOILER SCALE?

Many engineers consider any kind of depositions in a boiler as scale. Others only include deposits that require mechanical cleaners for their removal.

From a practical standpoint, any formations over the water-exposed surfaces which add to the fuel bills and necessitate cleaning or repairing of boilers can be classed as boiler scales. The hard setting and adhering properties, and the actual amount, are all factors in the increased costs due to scale.

When facts of this kind are correlated with the complete mineral analyses of scale deposits, a means is provided for recognizing the depositions according to their influence on boiler operating expenses. By including the chemical treatments in use with the complete mineral analyses of the feedwaters, as these apply to specific cases, more facts are presented by which their influences can be predetermined. Where an experience in the conditioning of boiler feedwaters has included records of thousands of scale and water analyses and of the various treatments in use for periods of up to 35 years, these facts become measures of the most definite type for registering the influence of any contained constituents, in either the feedwater or scale, on boiler operating expenses. This is probably best exemplified in the following analyses of different kinds of scale deposits listed according to the order in which they usually prove themselves objectionable from the standpoint of the expenses they incur:—

SCALES

Aluminum Sodium Silicate

Analyses	A	B
Silica	50.47%	46.6 %
Iron oxide	9.20 "	7.68 "
Aluminum oxide	6.07 "	3.32 "
Calcium oxide	17.79 "	32.0 "
Magnesium oxide	.70 "	.83 "
Sulphuric anhydride	.08 "	None

While these are the rarest of the silica depositions they invariably prove extremely difficult to remove with mechanical cleaners or chemical treatments. They are mostly the product of waters where the precipitating solids are under one grain per gallon and percentage of silica and free soda is high in relation to these solids. They prove so objectionable as to frequently cause tube losses where the thickness of this deposit may not exceed 1/100 of an inch. Again, high phosphate concentrations alone within the boilers fail to prevent them and the higher soda concentrations actually increase their formations.

Calcium and (or) Magnesium Silicate

Analyses	A	B	C
Silica	9.00%	31.5 %	54.9%
Iron and aluminum oxide	10.20 "	37.4 "	5.2 "
Calcium oxide	36.0 "	17.8 "	40.0 "
Magnesium oxide	12.40 "	4.05 "	5.4 "
Sulphuric anhydride	Trace	None	.5 "

What has been said about aluminum sodium silicate applies to high silica combinations with calcium and magnesium. Natural waters, where the silica is high as compared to its total contained precipitating solids, prove most troublesome in this connection. Mountain waters are the frequent sources of such supplies. Any pre-treatments of feedwaters that will reduce the precipitating solids without changing the quantity of silica, constitute other sources for high silica scales. Industrial waters of any kind are subject to such transformations. *In the final analysis, it is the percentage of silica in relation to the other precipitating solids in feedwaters and (or) the percentage of silica in scales, that measure the extent of their influence on boiler expenses.*

Calcium Sulphate

Analyses	A	B	C
Silica	12.93%	6.90%	3.2 %
Iron and aluminum oxide	5.74 "	.88 "	7.2 "
Calcium oxide	32.74 "	37.38 "	34.0 "
Magnesium oxide	12.35 "	4.87 "	1.65 "
Sulphuric anhydride	5.61 "	32.0 "	88.4 "

The calcium and sulphate radicals are common constituents in most industrial water supplies. Where these are used in the raw state or are incorrectly treated, depositions of calcium sulphate result, the percentage depending upon the sulphates present in the supplies in use. It is highest in those sources from the mines and industries wasting sulphates and acids into the streams. Unlike silica, all sulphate scales can invariably be entirely prevented with soda ash. In boiler operations, sulphate scales prove less active in causing tube losses, are much easier to remove, both mechanically and chemically than silica, and cost very much less in chemical treatments to prevent them.

Iron

Analyses	A	B	C
Silica	4.33%	4.45%	13.03%
Iron and aluminum oxide	12.61 "	39.07 "	72.0 "
Calcium oxide	39.72 "	22.76 "	6.0 "
Magnesium oxide	3.13 "	6.55 "	2.0 "
Sulphuric anhydride	.38 "	.67 "	2.90 "

Depositions of this kind result through corrosion within the feedwater heating equipment and boilers, or through introduction of iron itself to the boiler through the feedwater supply. Periodic internal inspection of the boilers, or of specimens of boiler steel located within the feedwater loop and within the boiler themselves, with an occasional analyses of the feedwater, is the logical means for determining the source of the iron in any deposit. Burnt-out tubes or difficult cleaning jobs rarely result because of iron scale deposits and only where silica is a prominent constituent.

In summarizing this whole scale situation—that set-up which will keep the cost of cleaning and repairing boilers, together with the costs of conditioning feedwaters, down to the practical minimum, is the objective most desired in any power plant operation.

PHOSCALOID, the recent product of the Rice Laboratories, is now proving the real answer to this in practice because it is correcting the worst scale problems with minimum sludge formations, and at the lowest possible costs.

Cyrus Wm Rice, *President*

CYRUS Wm. RICE & CO., Inc., Highland Bldg., Pittsburgh, Pa.

EDITORIAL

Fitting the Program to the Time

At this year's Annual Meeting of the American Society of Mechanical Engineers a technical program of more than a hundred papers and reports was crowded into three mornings and three afternoons. Of these forty were of primary interest to power engineers. It was inevitable that, despite such planning as was possible under the circumstances, many papers on kindred subjects were presented at simultaneous sessions. Because of this, members were frequently heard to express regret that they were unable to listen to certain papers and discussions in which they were much interested. Inasmuch as some of the papers and reports were not printed in advance this situation was unfortunate.

There is much to be said in favor of a three-day program, especially at present when the demands of industrial recovery are making it difficult for many engineers to remain away from their offices. Nevertheless, it might be well to keep the number of papers commensurate with the time available for their presentation, as crowding of the program always tends to limit worthwhile discussion.

The papers this year were, on the whole, of a high grade. A considerable number were of a highly technical nature and, as was quite apparent, were "over the heads" of many in the audience. Such papers have an important place in the work of the Society but their presentation in full at the Annual Meeting sessions takes up valuable time and penalizes the majority for the benefit of a few. Might it not be better, therefore, to present such papers in abstract, together with the conclusions, leaving their presentation in full to the *Transactions* where, together with written discussions, they can be studied at leisure by those most concerned. Such a procedure would release time for allocation to those papers of interest to greater numbers within certain groups.

Admittedly the problem is a difficult one in view of the diversity of interest within the membership and the important work going on within the field of mechanical engineering. It is one that warrants helpful suggestion rather than criticism.

New Light on Turbine Blade Deposits

The investigation on contamination of steam resulting in turbine blade deposits, as reported by Professor Straub, throws new light on a very troublesome problem and may well lead to its ultimate solution. His laboratory studies indicate that sodium hydroxide in the boiler water is the principal offender in that it provides the stickiness by which the entrained solids or salts are caused to adhere to the blades, and that this condition may exist even when the total solids in the steam are very low. By neutralizing the hydroxide with carbon dioxide or by adding sufficient sodium sulphate he found that the deposits would not form in appreciable quantity. These conclusions were verified in at least one large power station which had previously experienced much difficulty from such blade deposits.

Discussion of the paper was at variance with some of the author's conclusions, particularly that the deposits are independent of the steam temperature. The absence of deposits on impulse blading and their formation in certain lower reaction stages suggests that the sodium hydroxide freezes out of solution when the steam reaches about six hundred degrees. Furthermore, experience in some cases has indicated that velocity of the steam may be a factor. It will be recalled that the laboratory investigations involved impingement of the steam on a single blade only and thus did not simulate its expansion through the many stages of an actual turbine.

The suggestions brought out in the discussion may be regarded as pointing the way to further investigation of the subject and detract in no way from Professor Straub's contribution toward the solution of this problem.

A Demand for Young Engineers

It is an encouraging sign that the deans and professors of several engineering schools report a demand from industrial concerns for junior engineers, preferably those who have had two or three years' engineering experience since graduation. Inasmuch as most schools endeavor to keep in touch with recent graduates many firms in normal times were in the habit of contacting young engineers through such channels and it is gratifying to learn that this practice is being resumed.

However, because of the number of graduates that were forced to seek employment in other lines during the past three or four years, the professors are finding it difficult to meet the experience specification in such requests. This need not be an obstacle, for the young engineer who is still bent upon following the profession for which he was trained is likely to return to it with a broader viewpoint as a result of enforced experience in other lines. In fact, the vicissitudes of the depression period in many cases brought out latent traits in young engineers that periods of normal employment would not have developed.

There are indications that the demand for young engineers is about to be paralleled in the case of more seasoned engineers, the essential difference being that specialized experience is usually required of the latter.

Modernizing the CONNERS

Stokers and Combustion Air Control

By SABIN CROCKER
Engineer, The Detroit Edison Company

The first of this series of articles, which appeared in the November issue, discussed broadly the economic and engineering considerations involved in the program for rebuilding Conners Creek Power Plant. In the present article the stokers are described and the development of the combustion air control and its functioning are discussed in detail. The third article, scheduled for January, will deal with features of the new boilers which aided in trebling the steam generating capacity within the old column spacing; also with a discussion of how the existing coal handling, preparation and storage arrangements, and the method of ash removal, are able to serve a double capacity plant with only minor alterations.

THE choice between stoker and pulverized-coal firing for Conners Creek came as a result of some twelve years' intensive study of both methods. Trenton Channel, which commenced operation in the summer of 1924, is the Company's first, and so far only, pulverized-fuel station. At the time this method of firing was adopted for Trenton Channel its higher first cost and extra power for pulverizing were justified on the grounds of some two to three per cent higher average boiler efficiency than was expected with the then available stokers. Operating results for a period of over ten years have borne out these expectations, and there are no regrets over the adoption of pulverized-fuel firing at Trenton.

However, the appearance of the stack gases coupled with the collection and disposal of pulverized-coal ash present a problem which would be more pronounced for a plant within the city proper than for one some eighteen miles removed as in the case of Trenton. To the casual observer in the neighborhood the characteristic appearance of the stack gases from stoker firing is likely to be less disturbing than that from pulverized coal, especialy if the stoker be equipped with zoned air control. The actual appearance of the stack gases from the new Conners Creek boilers with their improved combustion air control is surprisingly uniform and shows to advantage even over previous stoker-fired plants in that the smoke is merely a whitish haze with no suggestion of brown coloring.

The various means of disposal for pulverized-coal ash all present some complications. What to do with the ash which has been caught at Trenton Channel still remains a problem now that available low ground around that plant has been sluiced nearly full. Since government regulations do not permit dumping ash from scows in the Detroit River or in Lake Erie or Lakė St. Clair, considerable attention has been given to ways and means of using it in the manufacture of building block. The outlet of block for construction purposes is limited, however, especially in these times, while on the other hand there is always a market for the cinders from stoker firing.

In so far as Conners Creek is concerned, the decision in favor of replacing the old stokers with an improved design embodying the latest developments in combustion air control rather than switching to pulverized coal was affected materially by the ability to re-use the old bunkers and coal-handling equipment. The coal-unloading house, crushers, conveyors, bunkers, etc., which served the fourteen boilers in the old plant were available practically without alteration and undisturbed to serve fourteen new boilers. The only change actually required was to provide new feeder pipes with "Conical" spreaders between the bunkers and the stoker hoppers.

Consequently, the Company has sought to perfect the design of its stoker installations to the point where the efficiency and rates of evaporation obtained with stoker firing would approach those possible with pulverized coal. The desire to obtain high efficiency, coupled with the need for doubling or trebling boiler output within the limitations of the old column spacing, fitted in with the Company's earlier work in applying combustion air control to stokers. In view of the importance of this phase of the rebuilding project, the air control for Conners Creek is described in some detail, with an historical account of the earlier phases of its development in the other stoker-fired plants of the Company. Further information regarding the coal handling and preparation plant is given in a later article.

Description of Stoker

Allowing for differences between single-ended and double-ended design, the stokers under the new boilers (see Figs. 9, 10, 11, 12) are so intimately related to the Delray Power House, No. 3 stokers and so directly a result of experience gained there that a brief review of that installation[1] would be a fitting introduction

[1] For greater detail, see "Stoker Developments at The Detroit Edison Company's Delray Power House No. 3," by P. W. Thompson and F. J. Chatel, *Trans.* A.S.M.E, FSP-55-11, 1933.

CREEK POWER PLANT-II

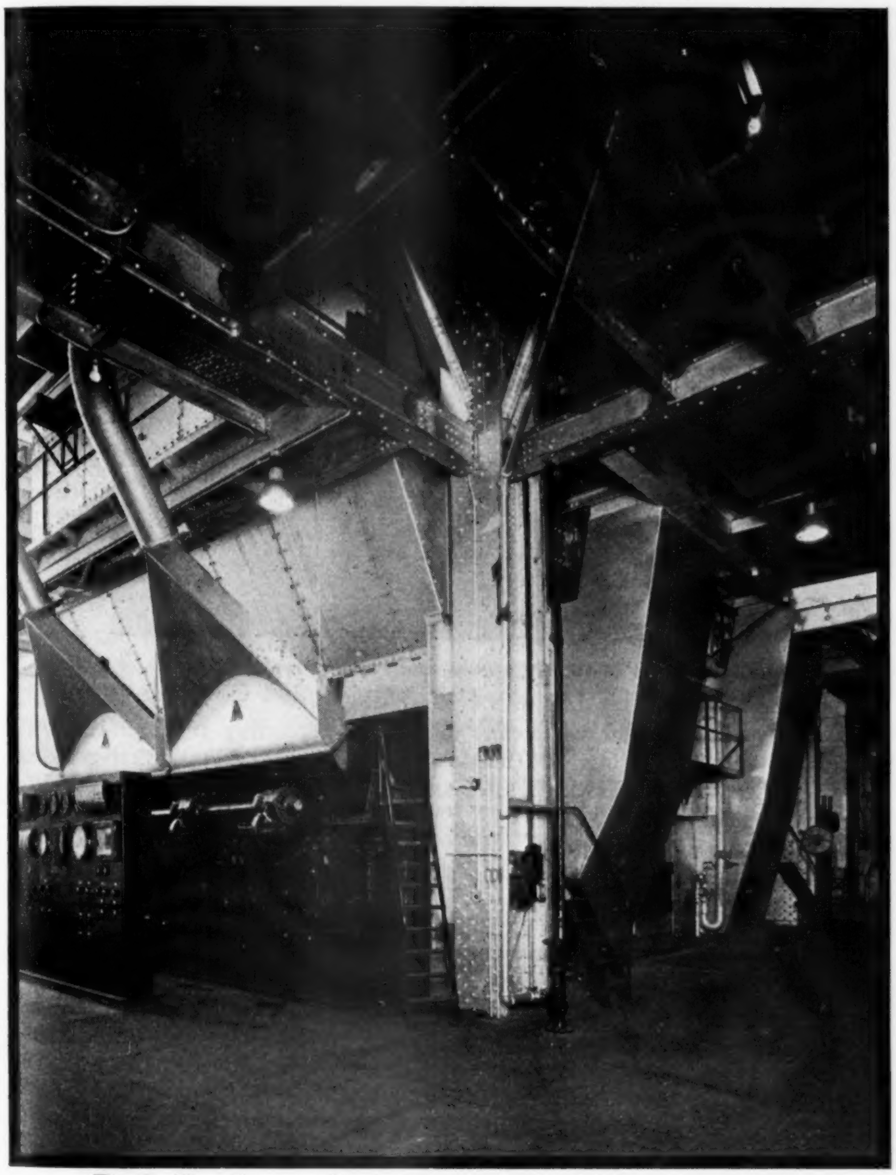

Fig. 9—New Conners Creek stoker and controls from operating floor

the fuel bed over the end retorts. The amount of iron burned was also reduced by the installation of these slag deflectors in connection with water-cooled furnace block in the clinker zone (shown in Figs. 10 and 11); by the more uniform coal distribution resulting from redesigned coal chutes and the better elimination of entrained foreign matter; and by the improved distribution and better control of combustion air. Changes in mechanical design and use of properly heat-treated materials were made to reduce maintenance.

Operating experience at Delray led to improvements in the new Conners Creek stokers. The continuous coal-burning rate for which the Delray stoker was designed was easily met and could have been exceeded were it not for limitations imposed by the accumulation of slag on the water-screen and superheater tubes. One stoker was operated for 299 steaming hours with preheated-air temperatures as high as 500 F. Examination of the stoker after the test did not show any burning attributable to the high air temperature. While the automatic air control developed for Delray proved to be an aid to efficient combustion, the superior performance of the Conners Creek air control, described later, influenced the Company's engineers to replace the original Delray control with the Conners Creek type, making such changes as seemed called for to suit a single-ended stoker and other items peculiar to Delray.

to a description of those at Conners Creek. The Delray single stoker indicated that the four-pusher arrangement was superior to the six pushers originally installed, in producing flue gases richer in CO_2 and in making it possible to burn efficiently a wider range of fuels. Accordingly, for the Conners Creek double stoker, where the coal travel is cut in half, an equivalent arrangement using two rows of pushers for each side was provided.

Clinker formation in the Conners Creek furnaces was reduced by several means, including: better packing of coal in the retorts as a result of fewer pushers; a change in shape of the bottom pusher; and installation of side-wall slag deflectors arranged in steps above several horizontal rows of blocks shielding the tubes (see Fig. 10). These deflectors help to reduce the formation on the side walls of slag sheets which tend to build up from

The fuel-burning unit at Conners Creek consists of a double-ended stoker having two twelve-retort sections opposed, and a nominal length of 29 standard tuyères. A new center-divided thin tuyère, of which there are 41 per stack, is being developed as better adapted for use with the combustion air control. A sectional side elevation of the stoker is shown in Fig. 12.

Each retort has a $9^1/_2$-in. ram, two pushers and a moving extension grate. Low ram-box caps are in use, but they are designed to permit substitution of a new casting so that the height can be increased if necessary to provide an initially heavier fuel bed. The upper pusher has a square nose, while the bottom pusher has a long beveled nose found by earlier experience to be particu-

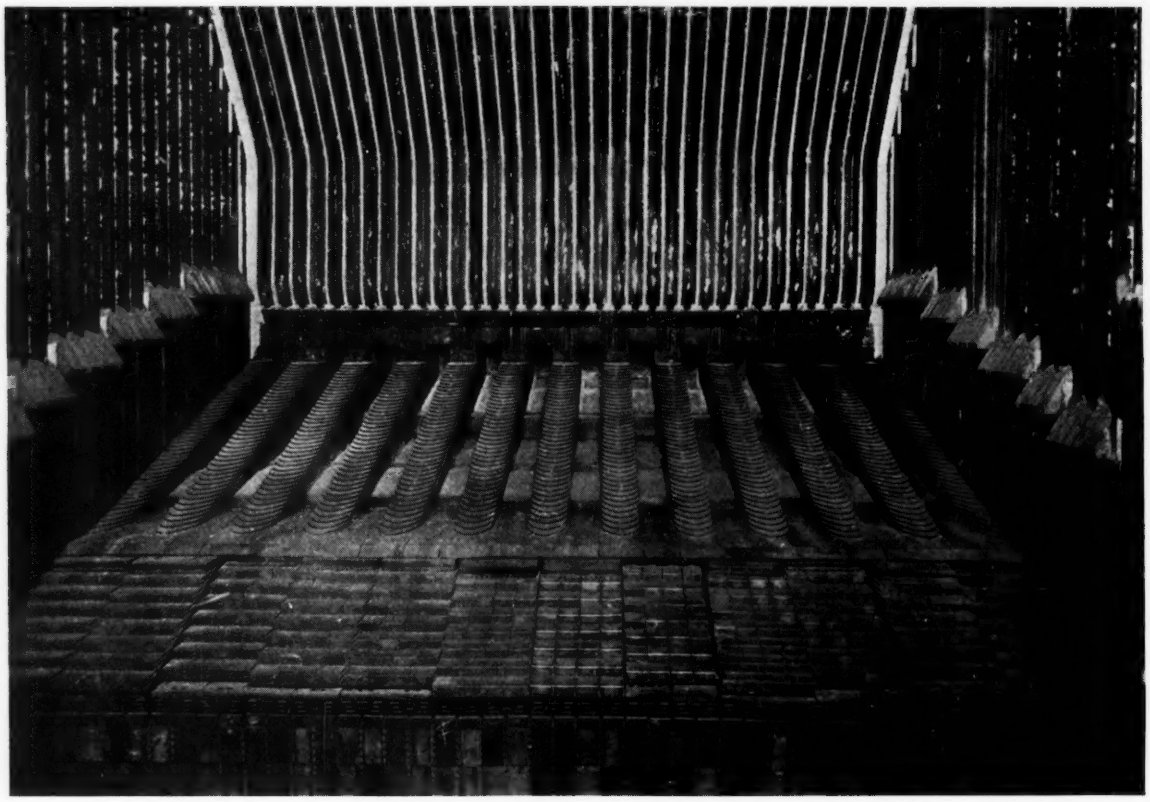

Fig. 10—View inside boiler showing coal retorts, tuyere stacks and furnace walls

larly adapted for the removal of clinkers from tuyère plates and coal-plate extension noses. The pusher installation conforms with Delray experience where it was found that fourteen to fifteen standard tuyères per pusher gave the best results with the coal in use.

A typical analysis of the West Virginia and eastern Kentucky coal which is generally burned on these stokers is given in Table IV. In the proposed A.S.T.M. tentative specification D388–34T for the classification of coal by rank, this coal is designated as "high-volatile B bituminous." The double stoker with the ashpit has a projected area of 557 sq ft and is designed for *normal* continuous coal burning rates up to 32,500 lb per hr and *maximum* continuous rates up to 42,000 lb per hr with good coal. The latter provision insures holding normal boiler output even with the poorest grade of coal expected. Design conditions for operation of the new Conners Creek stokers are shown in curve form in Fig. 13 and expected performance for a wide range of loads in Table V.

TABLE IV—TYPICAL ANALYSIS, GOOD COAL

Proximate analysis:	As Fired	Dry Basis
Moisture, per cent	5.40	
Volatile matter, per cent	32.13	33.96
Fixed carbon, per cent	54.66	57.78
Ash, per cent	7.81	8.26
Heating value*, Btu per lb	13,340	14,100
Ultimate analysis:	**As Fired**	**Dry Basis**
Carbon, per cent	73.84	78.05
Hydrogen, per cent	5.54	5.22
Nitrogen, per cent	1.49	1.58
Oxygen, per cent	10.38	5.90
Sulphur, per cent	0.94	0.99
Ash, per cent	7.81	8.26
Ash-softening temperature, 2500 F or above.		

*NOTE: Gross Calorific Value, Hs (products of combustion cooled to room temperature), as defined by tentative designation of A.S.T.M. Committee D-5 on Coal and Coke.

To facilitate clinker grinding, the ashpit is supplied with a small but continuous quantity of general-service water by means of nozzles extending through the top casting of the lower grates. Double clinker-grinder rolls (see Figs. 11 and 12), the shells of which are 20-in.

TABLE V—EXPECTED STOKER PERFORMANCE—GOOD COAL

Coal burning rate, lb per hr	6,000	16,000	24,000	32,500	42,000
Coal burning lb per sq ft per hr	10.8	28.7	43.1	58.3	75.4
CO_2 at boiler outlet, per cent	15.0	15.4	15.6	15.7	15.7
CO at boiler outlet, per cent	0.02	0.02	0.04	0.13	0.30
Combustible in refuse, per cent	8.0	6.0	9.0	12.0	
Speed of stoker crankshaft, rph	16	44	66	89	113
Stoker horsepower per boiler	3.5	6.4	8.4	10.5	13

diameter, are operated intermittently when needed to pass ash and clinkers in the ashpit on into the ash hopper above the railroad tracks. The grinder rolls, which have an adjustable speed range of 48 to 1, obtained through a variable-speed motor drive and a selective engagement of a ratchet and pawl, crush the clinkers against adjustable aprons to a size which can drop through into the ash hopper.

Since the driving mechanism overhangs the front support columns, the stoker is often referred to as the "cantilever" type. The weight of parts outside the boiler, including the power boxes, are amply counterbalanced by the weight of fuel bed and stoker parts inside the setting. The lower end is supported on rollers to reduce frictional resistance to heat expansion. Measurements of this expansion will be discussed under "Operating Experience Suggests Design Improvements." The drive for each stoker is by a $3^1/_2$- to 15-hp dc motor which has a 4 to 1 speed range and operates through a two-speed silent gear reducer ($2^1/_2$ to 1), and four power boxes equipped with two-speed planetary transmissions ($1^1/_2$ to 1). With these speed reducers and use of full and half-voltage on the motor, it is possible to obtain a total speed-range control of 30 to 1.

The power-box planetary assemblies incorporate all the improvements of design and material effected at

Delray. These improvements consist in the use of better matched materials and the machining of gears and bearings to an accuracy and clearance standard approaching that of a well-made automobile transmission.

Operation of the stoker drive can best be explained by reference to Fig. 12. Each power box serves a three-piece bolted crankshaft in one stoker section of three retorts. The crankshaft, through a connecting rod, operates a three-throw bell crank pivoted at the bottom of the crankshaft brackets, which in turn motivates simultaneously the ram, pushers and moving extension grate. This "straight-line drive" has a desirable feature in that the small angularity between the ram connecting link and the line of travel of the ram reduces wearing of the bearings and rubbing surfaces, and lessens the possibility of the ram's binding. On the lower part of the bell crank is a trunnion which carries a rod through which the mechanisms of the coal pushers and extension grates are activated. Length of stroke is adjusted by horseshoe washers. Pusher rods enter the plenum chamber through outside stuffing boxes and are connected to the pushers through levers to reverse the motion. The pusher-link and pusher-lever bearings beneath the stoker, as they cannot be lubricated, are made of hardened-steel pins and bushings with $^1/_{16}$-in. clearance.

Some mention should be made of salvaged material from the old stokers. Two power boxes with the dc motors and controllers of the old stokers were rehabilitated to operate the clinker grinders on each of the new boilers. The dc controller for the new stoker motors is made up completely of salvaged material and parts put together by the Company's own construction shop. The rotary coal valves admitting coal from the bunkers to the new "Conical" spreaders are also salvaged equipment.

Center-divided tuyères and tuyère boxes were used at Conners Creek to place the air supply going to both sides of each retort under the same control. Fig. 14 shows two types of center-divided thin tuyères developed for this purpose and now in experimental use on the new boilers. The aim is to make the control areas for both air and coal coincide rather than overlap, thus obtaining better regulation of combustion in the fuel bed. This arrangement is shown diagrammatically in Fig. 15 in comparison with an earlier overlapping air control.

Operating Experience Suggests Stoker-Design Improvements

Operating experience at Conners Creek so far has indicated the need for few changes in the design of the stoker; such changes as have been required involve only minor components and do not affect major design. These improvements have been incorporated in the stokers for the new boilers Nos. 3 and 4.

CANTILEVER SUPPORT: Due to the location of the principal support (see Fig. 12) it was feared that thermal expansion of the cantilever-type stoker would cause an outward and downward movement of the external driving mechanism which would result in excessive wear of the crankshaft and crankshaft bearings. Careful checks by means of reference marks placed on the stoker and on nearby supporting steel have shown outward movements from the cold position of $^3/_{16}$ in. at the end-bearing brackets and $^3/_{32}$ in. at the center brackets. Downward movements of $^1/_{16}$ in. have been recorded on some of the end brackets. To minimize this movement, as well as to make a tighter and more rigid stoker front, the former assemblage of supporting columns and connecting castings has been replaced in the later units by a steel-plate girder which extends the entire width of the stoker. Slight improvements have been made in the crankshaft bearings.

REPLACEABLE REFRACTORY: These have been placed on the moving extension grates (see Figs. 10, 11, 12) for protection of the castings which have heretofore been a vulnerable point. It now appears that the characteristics of the coal supplied to the Detroit area are such that this refractory material withstands the fluxing action very satisfactorily. Although the lower blocks are somewhat affected by erosion, their replacement has been infrequent and the cost has been kept low by transferring the bottom blocks when badly eroded to the upper positions where wear is less severe. Performance of this refractory is such as to warrant placing similar blocks at the noses of the coal-plate extensions and the tuyère plates.

RENEWABLE CAST-IRON BLOCKS: Stationary lower grates extending from the bottom of the moving grate to the crusher aprons are made up of cast-iron blocks (see also Figs. 10, 11, 12). Some distortion which was observed in these blocks has been reduced by using a reinforcing web in the back of the block. Reinforcement of the upper edge of the top pusher has minimized burning. Some benefit may result from a study directed toward improving the flow of fine wet coal, the improper distribution of which has caused considerable operating difficulty and increased stoker maintenance during winter months.

TUYÈRES: As to the tuyères proper these stokers give promise of establishing a new standard of low replacement costs attributable primarily to the uniformity of air distribution brought about by the system of metered

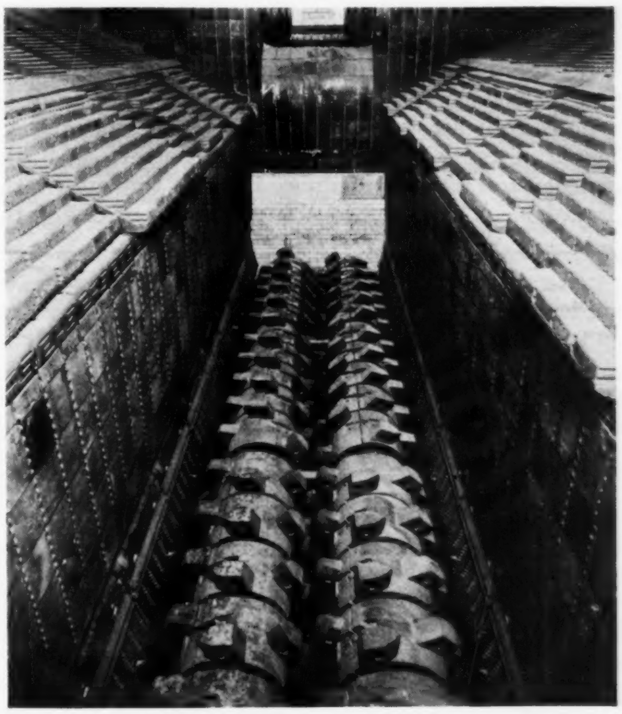

Fig. 11—View inside boiler showing reciprocating extension grates, shingle grates and clinker grinders

air control as will be explained in detail later. It is possible that further improvement will be effected by refinements in the design of tuyères. Observations are still being made on both the blunt-nosed tuyère in boiler No. 1 and the stream-lined tuyère in boiler No. 2. The stream-lined tuyère, designed and checked under smoke-bomb and pitot-tube tests for uniform flow of air through all ports, is used for the new stokers for boilers Nos. 3 and 4. A study is going forward to improve the design of the cross-division plates under the top tuyère and between the 18th and 19th tuyères. Some interference with the operation of the air control for the extension-grate zone was caused by siftings. To provide a siftings hopper, the controlled air was redirected and introduced at the top of the extension-grate air duct with a separate duct installed to draw off the siftings.

Slagging: The adherence of molten fly ash to the water-screen tubes which shield the superheater from the furnace has been an obstacle to the continuous operation of the stoker at high rates of combustion. Slagging of these tubes has tended to limit the length of time during which high steaming rates could be maintained continuously without temporarily lowering the output sufficiently to cause temperature descaling. Conditions have been greatly improved through providing, on the furnace side of the water-screen tubes, special soot-blower nozzles supplied with steam from integral soot-blowing elements welded to the back of the tubes. Removal of slag by an occasional blow of steam has so far been successful enough to warrant the expectation of continuously maintaining high boiler output. A complete account of the soot-blowing equipment will be given in a later article describing the boiler.

Need for Combustion Air Control

Conventional stokers have been handicapped through inability to regulate properly the flow of air to various zones of the fuel bed. The rate of combustion must be held down to suit limiting conditions imposed by: (*a*) thin spots in the fire; (*b*) the zone of fresh coal which is more easily lifted or torn apart by a strong air blast than after the fuel has coked; (*c*) the tendency for combustion to proceed at excessive rates in some zones before high enough rates have been reached in others; (*d*) the tendency to build up resistance in spots through clinker formation. The advantages of metered control and the means for overcoming the foregoing limitations are described below.

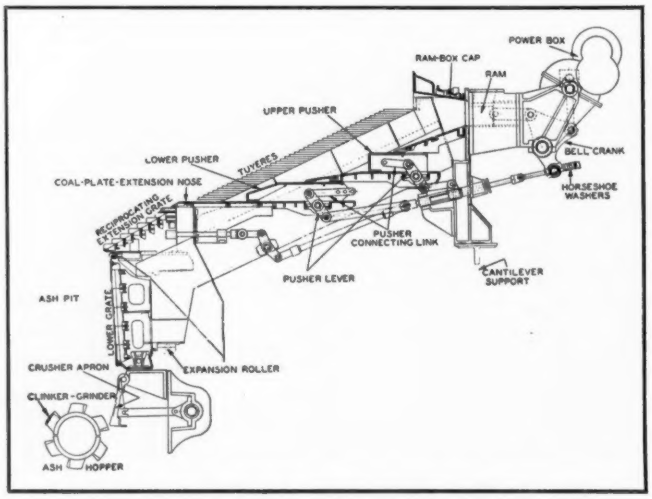

Fig. 12—Cross-section of stoker (one side only)

In a stoker not having such air control, combustion in small areas having excessive fuel-burning rates may reach 250 lb or more per square foot per hour although the average rate may be only 60 lb for the whole stoker. The function of air control is to hold combustion rates within bounds in the fast spots and at the same time bring up rates in the slower regions, thus increasing the average rate for the entire stoker without exceeding the limiting conditions of operation. Elimination of excessive combustion rates in susceptible areas tends toward reduced maintenance and greater continuity of service. A further advantage is a pronounced decrease in smoke, particularly at high ratings.

That the tuyère openings throughout a stoker are of uniform size may have led to the unsound assumption that air distribution in a conventional stoker is likewise uniform. This would be approximately true if the resistance imposed by the tuyères to air flow were the controlling factor, which actually is not the case. At maximum output with the original Beacon Street boilers the total differential between plenum chamber and furnace pressures was about six inches of water. Of this, about half an inch was dropped through the tuyères, the remainder being almost entirely pressure drop through the fuel bed. Since air distribution is controlled by fuel-bed resistance rather than by the size of the tuyère openings, variation in fuel-bed resistance at different points means unequal distribution of air.

Recognizing this condition, it is not difficult to find an explanation for fuel-bed disturbances with the conventional stoker. The upsetting process usually starts at some point in the fuel bed, never entirely homogeneous, where there is a slightly increased flow of air. This condition, in turn, causes a locally increased combustion rate which makes the fuel bed tend to burn still thinner at that point and allows the flow of air through that area further to increase. The thin spot presently becomes a hole that cannot fill up because of the blast of air from the tuyères, and large pieces of coke are blown to other parts of the furnace. Simultaneously, in another part of the furnace the reverse of this action may be taking place, the fuel bed there becoming locally thicker and the air flow being cumulatively restricted. In a large furnace this process, if allowed to continue, results in an extreme amount of unevenness and may eventually render the fire totally unmanageable.

Obviously, a high combustion rate cannot be maintained under such conditions even when ameliorated by changes in the coal feed and length of pusher stroke. This extreme disrupting process requires a certain time for completion, varying from a few minutes to an hour or more, which explains why it was often possible with stokers not having such air control to carry high combustion rates for short periods, but not for a considerable time. At high combustion rates changes in the fuel bed take place rapidly and, when no variable air control is installed, the unbalancing may be well under way before it is observed by the operator, who normally must depend upon visual inspection of the fire.

Evolution of Zoned Air Control

The Detroit Edison Company, since its earliest experience with large boilers, has been interested in meth-

ods of controlling and distributing air to underfeed stokers. About ten years ago it decided to avail itself of a development being carried on by Mr. Maxwell Alpern, then president of the American Engineering Company, for subdividing the supply of combustion air for an underfeed stoker into control areas arranged egg-crate fashion underneath the entire fuel bed. After some experimentation with models and in the boiler plant of his own company, Mr. Alpern had tried out his scheme on a larger scale in one of the boilers in the Edgar Station of the Edison Illuminating Company of Boston.

Starting with an experimental installation in 1927 under one of the boilers at The Detroit Edison Company's Marysville Power Plant, successive installations were made at Delray Power House No. 3 in 1929, and at Beacon St. Heating Plant in the same year. While the installation at Marysville, which has since been taken out, was not all that might be desired, results were sufficiently encouraging to warrant proceeding concurrently with an automatically-operated combustion-air control at Delray and a manually operated system at Beacon Street. The information gleaned from these three pilot installations has led to the development for the new Conners Creek stokers of an improved air-control system which has realized practically all of the objectives set for it.[2]

Results from the recent installation at Beacon Street demonstrated on test, first that the sustained maximum fuel-burning rate for a given stoker can be increased at least twenty-five per cent through air control, provided fan capacity permits, and second that the boiler efficiency is raised appreciably, the increase ranging from about two per cent at low steaming rates down to $^1/_2$ per cent at high rates. The importance of this increase in the combustion rate will be appreciated when it is considered that the installation of the control system on the four existing boilers of the Beacon St. Plant would provide as much steam generating capacity as would an extra boiler. The increase in efficiency, if maintained in daily operation, would in itself be sufficient to pay the increased cost of the control equipment with the decidedly better load factory obtaining in a power plant.

The idea of regulating the air flow for each control area through its own orifice and utilizing changes in pressure differential across the orifice to actuate its own and adjoining dampers for the purpose of automatically maintaining a constant aggregate air flow through the group was proposed by Mr. Alpern. As developed in the initial combustion-air control for Delray No. 3, constant aggregate flow was obtained through interlocking the controls in such a way that if the air flow through one area was increased, flow through adjoining areas was decreased a corresponding amount, and vice versa. An overcompensating characteristic was built into the system so that any correction in the air flow tended to go temporarily too far in the new direction. This feature, coupled with the fact that the Delray control did not respond to small enough changes in pressure differential, failed to produce a sufficiently stable fire to be considered wholly satisfactory, and as a result the functioning of the control device had to be backed up with an excessive amount of manual adjustment. These shortcomings have led to the replacement of the original Delray controls with the new Conners Creek design.

[2] For greater detail see paper on "Distribution of Air to Underfeed Stokers," by A. S. Griswold and H. E. Macomber presented before the Fuels Division at the Annual Meeting of the A.S.M.E., December 1935.

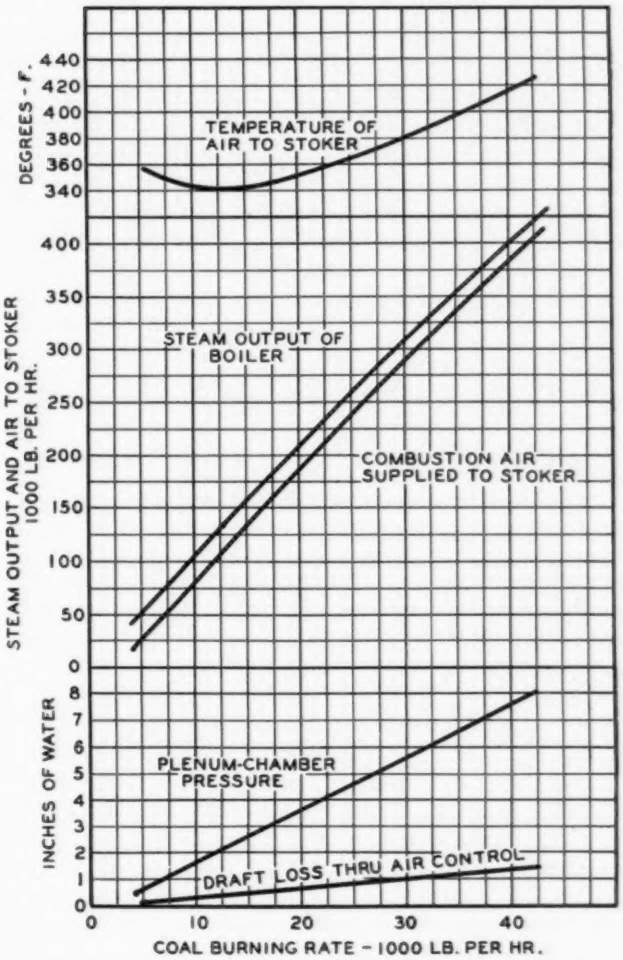

Fig. 13—Design conditions for stoker operation

In developing an automatic air control for the Conners Creek boilers it was decided, therefore, to proceed along different lines which would anticipate and immediately counteract any tendency for change from uniform air flow rather than depend on overcompensating devices or manual adjustment. In the Conners Creek system individual areas have their own air-flow regulators which function separately and at the same time are ganged up with the regulators for other areas in the same row to establish horizontal zones crosswise of the stoker. Air flow through these zones, usually three for each half of a double-ended stoker, can be given any desired bias between zones to suit best the progress of combustion as fuel advances through successive zones. A general idea of the principles of this control can be had from Figs. 16 and 17. This system is sometimes referred to as "zoned air control," since the dual aim is to maintain equal air flow through all the areas of any one zone and at the same time give a certain amount of bias to rates of flow in different zones.

The functioning of the Conners Creek air control is improved by the fact that the boiler setting and stoker are superior to the early installations where considerable air required for combustion leaked in by infiltration through the furnace walls, around the pushers and up through the ashpit. The initial Delray installation clearly demonstrated among other things the effect of air infiltration upon the performance of the air heaters, and the need for tight settings. Through close attention to minimiz-

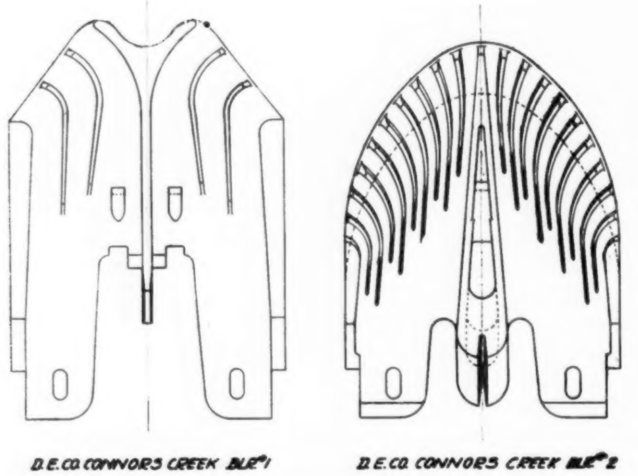

Fig. 14—Two types of center-divided tuyeres

ing such leakage in the Conners Creek design it has been possible to make a striking reduction in excess air with a corresponding increase in CO_2, and despite the small amount of excess air practically to eliminate smoke at all ratings.

To the use of zoned air control at Conners Creek is attributed ability to burn about 25 per cent more fuel on the grate area which can be installed within the existing building columns. Since fuel burning capacity would otherwise have been the limiting factor for boiler output, installing the control on twelve boilers will make it feasible to omit the thirteenth and fourteenth boilers from the ultimate plant and thus lower the investment by about one and a half million dollars. The saving obtained through omitting two boilers, representing about six times the extra cost for air controls on the twelve boilers actually required, is over and above any reduction in fuel cost expected from the use of zoned air control which in itself should be sufficient to pay for the controls.

How Zoned Air Control Improves Combustion

Since the basic idea of zoned air control is to adjust the air flow to each small subdivision of the fuel bed independently to meet changes in its fuel-bed resistance, departures from the desired fuel-bed thickness do not change the flow of air in the affected area, and progressive unbalancing of the fire cannot even start. Of equal importance is the ability to distribute air in unequal proportions to the different zones extending crosswise of the stoker, thus obtaining optimum results best suiting progressively changing conditions of combustion as fuel moves down the stoker toward the clinker grinders. Experience with the Beacon Street installation having a cold-air supply has shown that, in this case at least, best results are obtained when the lower rows of tuyères are supplied more air than the upper. At high steaming rates about twice as much air was supplied to the lower twelve tuyère rows as to the upper seventeen. Reducing the supply of air to the upper tuyères permitted building up a more active fire at the lower end of the tuyère stacks and on the extension grates. With a stoker operating on preheated air, on the other hand, best results are obtained with a different amount and direction of the bias between zones. Different combinations may be needed with either cold or preheated air to obtain the highest efficiency possible with other types of coal.

Design Features of Conners Creek Air Control

The design of control worked out for Conners Creek embodies improvements in methods and application over those used in the previous installations. The original Delray job suffered because air flow to considerable portions of the stoker, such as the extension grates, was not controlled. This system was subject to a further limitation in that, while control for each of the several stoker areas was automatic, flow was not reported to the operator nor were the positions of the control dampers. The operator was, therefore, left entirely in the dark as to whether or not the overcompensating mechanism had successfully equalized flow between areas; neither had he any means of adjusting the relative air flow by horizontal zones to suit changing conditions of the fuel bed and the rate of combustion incidental to keeping step with changes in boiler output. Any corrections in the thickness of fuel bed in any area or areas had to be effected through adjusting the pusher stroke. Consequently, burnouts of stoker parts sometimes occurred when some area got out of balance unknown to the operator.

The manual control at Beacon Street reports, by meter readings at the gage board, the relative air flow in all of the several stoker areas, and affords a means for equalizing flow between sections in one zone and for proportioning flow as between zones. An air-flow reading greater or less than the average of other areas in the same zone is the operator's indication of a thin or a thick spot in the fire, or possibly of a clinker. After he has brought the air flow in the affected area back to normal by damper adjustment, the relative positions of the control buttons, which resemble a carburetor choke, serve to show where an abnormal area is located. When the presence of such an abnormal area is made known in this way, it is possible to take steps to correct the trouble, either through adjustment of the air control or the pusher rods on the coal feed, or both as circumstances warrant.

In designing an air control for Conners Creek it was the aim to have operation automatic in so far as practicable and at the same time provide an application of flow conditions in each area by which a manual readjustment of the automatic zoned air control could be made. The general scheme is shown in Fig. 17. Air for combustion is metered through venturi nozzles, twelve per zone or a total of seventy-two per double stoker. At the trailing end of the venturi box is a butterfly damper, the position of which determines the pressure differential between the inlet and the throat of the venturi and thus the air flow at a given plenum-chamber pressure. All the air supplied for combustion is metered and under automatic control, a relatively small amount entering above the stoker through the front-wall air boxes and a still smaller amount going to the shingle grate. The air to these points (marked *FWA* and *SGA*) is controlled by dampers set by hand from the operating floor. Each single stoker has its own plenum chamber fed by two air ducts. There is no cross-connection between the two plenum chambers of a double-ended stoker except that both are supplied by a single forced-draft fan per boiler

Description of Automatic Air Control

The following items comprise the automatic air control equipment for each boiler (see Fig. 17):

(1) One or more Master Venturi Nozzles (*MV*)
(2) One or more Master Controllers (*M*)

(3) Six Zone Regulators (*Z*)
(4) 72 Air Flow Regulators (*R*)
(5) 72 Power Cylinders (*C*)
(6) 72 Venturi Meters or Venturi Nozzles (V_1, V_2 and V_3)

Briefly, the control system functions as follows: Bias of air flow between zones is set manually by the six *handwheels, ZW,* which adjust spring tensions on the diaphragms of their respective *Zone Regulators, Z.* Relative quantities of air going to different zones are indicated quantitatively on the *Six-Unit Gage S.* Distribution of air to individual areas in any one zone is indicated by the *Twelve-Unit Gage G,* which can be connected to the zone desired by rotation of the *Gang Valve Operator P.* This twelve-unit gage was intended to afford a visual check on the uniformity of flow in the several sections of the zone. Since experience has shown the action of the regulators to be so correct and so sensitive that this visual verification can be dispensed with, the twelve-unit gage has been omitted from Boilers 3 and 4. The position of each set of dampers in the 72 *Venturis,* V_1, V_2, V_3, *etc.,* is reported at the gage board through an electrical meter operated by the piston rod of each of the 72 *Cylinders, C.* This provides a good indication of the condition of the fuel bed over each of the 72 controlled areas which has proved an invaluable guide in the management of the coal feed and pusher adjustment.

Thus far nothing has been said of the simultaneous adjustment of the 72 area regulators to correspond with changes of load on the unit. This requirement is met by the introduction of one or more master controllers which function as follows:

At any given plenum-chamber pressure a *Master Controller, M* can be set by its *Master-Venturi Damper, MD* either to (*a*) furnish the desired "loading pressure" to the diaphragms of the six *Zone Regulators, Z,* which in turn furnish biased "loading pressures" to the 72 *Air-Flow Regulators, R* according to the zone in which each is located; or (*b*) furnish loading pressure direct to twelve air-flow regulators where a master regulator is provided for each separate zone in lieu of the zone regulator previously mentioned. These and other schemes have been tried during the development of the control system. In either scheme if the plenum-chamber pressure remains constant, the settings of all the regulators (master, zone and area) will remain constant unless disturbed by manual adjustments of either the zone or master regulators as described later. With constant settings of all regulators, each area regulator will act automatically and almost instantaneously to maintain flow of air in its respective area.

Change in the output of the boiler as a whole is effected through changing the plenum-chamber pressure by adjusting the speed of the forced-draft fan or moving the position of its outlet damper, and changing the rate of coal feed to correspond. With a change in plenum-chamber pressure, sensed through the change in pressure drop across its *Master Venturi Nozzle, MV,* the one or more *Master Regulators, M,* then act automatically to change the air flow through all zones and areas to suit the new conditions. The functioning of the control system as a whole will be better understood from the following description of its component parts.

The *Master Venturi Nozzle* is a small replica of the 72 venturi nozzles under the stoker and has the same characteristics. This master nozzle allows a small leak-off from the plenum chamber to atmosphere or other region of reduced pressure and is equipped with a damper at the trailing end to introduce a resistance which can be adjusted manually to equal the average fuel-bed resistance plus the average resistance across the dampers in the 72 venturi nozzles.

The *Master Controller* responds to changes in differential across the master venturi nozzle, the leading connection going to one side of the large master-controller diaphragm and the throat connection going to the other side. The device contains both a large and a small diaphragm directly opposing one another and counterbalanced by an adjustable spring. A linkage attached to the rod connecting the two diaphragms operates a small air-leakage valve, similar to a pressure-reducing valve, supplied with compressed air at 8 lb per sq in. and delivers loading pressure to the small diaphragm as well as to the diaphragms of the six zone regulators where such are used, otherwise to the area regulators of one zone. The loads on the two diaphragms must balance one another plus the tension from an adjustable spring which is set at the time of installation to give the desired performance characteristic. Air from the master controller passes through a surge tank and orifice to a header supplying "master loading pressure" to the six zone regulators, or directly to a group of air-flow regulators as the case may be.

The *Zone Regulators* are spring-loaded single-diaphragm reducing valves which step down and adjust the 8-lb air pressure for loading pressure on the area regulators. The "master loading pressure" admitted on one side of the diaphragm together with the compression of an ad-

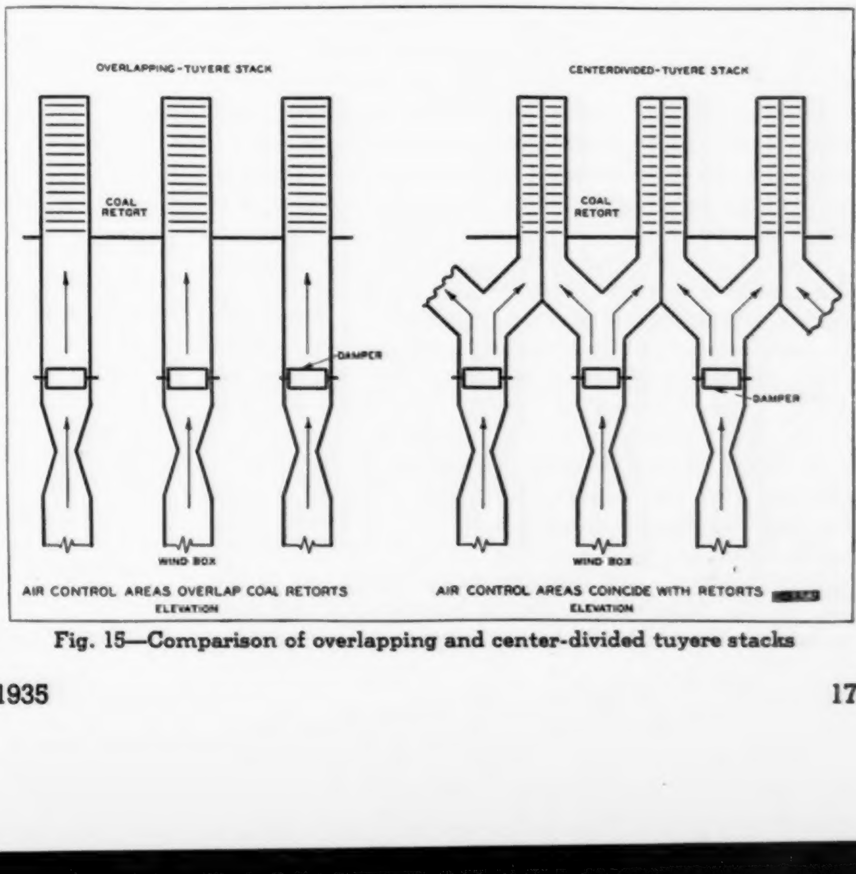

Fig. 15—Comparison of overlapping and center-divided tuyere stacks

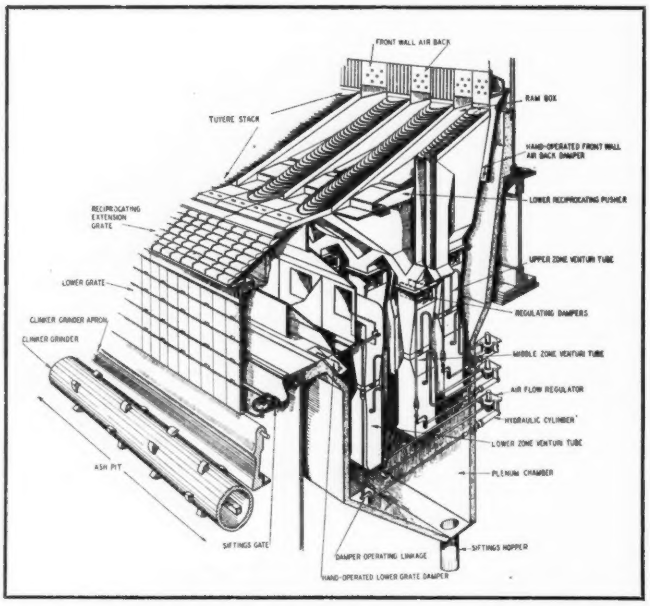

Fig. 16—Perspective view of the Conners Creek air control

justable spring on that side oppose the area regulator loading pressure on the other side. If the spring were not in compression the pressure of the air discharged from the zone regulator would be exactly the same as the "master loading pressure." By compressing the spring the delivery pressure from any zone regulator can be stepped up to simultaneously increase the loading pressure on all air-flow regulators in that zone by any desired amount up to 4 lb per sq in. Screw adjustment for compressing the spring is operated manually from a handle *ZW* on the boiler gage board through a chain and sprocket wheels.

Where zone regulators are used each furnishes loading pressure for 12 air-flow regulators, again through a surge tank with a $^1/_{32}$-in. orifice. The air-flow regulators act automatically under the bias supplied by the zone regulators to maintain a constant combustion-air supply to each stoker area in the same zone, as explained below. The master controller in this case actuates six zone controllers per boiler, which in turn may be set to give a bias to the combustion-air supply as between zones. Where the single master controller is omitted and a group of master controllers used in lieu of the zone regulators, bias is given between zones by extending the means for adjusting the outlet dampers of their master venturis up to the gage board where hand wheels are provided as in the first instance.

The *Air-Flow Regulators* are diaphragm-operated differential controllers. Here again there are two opposing diaphragms, a large one operating on differential pressure across the corresponding venturi nozzle and the other a small loading-pressure diaphragm. The two are solidly interconnected to operate a double-pilot ball-check valve through a lever, the fulcrum point of which is a flexible monel-metal plate separating the pilot-valve chamber from the diaphragm housing. The net load on the large diaphragm is opposed on the under side of the small diaphragm by the air loading as received from the zone regulators. The tension spring connected to the top of the large diaphragm is permanently adjusted to balance the weight of the diaphragms and compensate for inequalities in the regulators, thus coordinating the regulators of a zone. When the loads on the two diaphragms balance, the pilot valve is in neutral position admitting water at equal pressure to both sides of the piston of the power cylinder. Water is supplied to the pilot valve at approximately 50 lb per sq in. by a special pump taking its suction from the plant condensate storage.

If air flow through a venturi nozzle supplying any area should change due to a change in the fuel-bed resistance of that area the damper would automatically and immediately adjust itself to a new position which would restore uniform air flow. Assume for instance that the fuel bed thickens slightly, thus tending toward decreased air flow since the resistance has been increased. Decreased air flow means decreased differential and, as the loads on the two diaphragms of the air flow regulators no longer balance, the two diaphragms would move in an upward direction, thus closing the bottom pilot valve and opening the top pilot valve to admit water ahead of the piston which, in turn, would cause the latter to move away from the plenum chamber wall and open the dampers in the venturi nozzle. This action would progress to a point where the damper was opened sufficiently to again permit an air flow corresponding to the loading pressure. If the fuel-bed resistance should decrease the action would be directly opposite, and the dampers would close until the correct air flow had been established.

Since all regulators in a zone receive the same loading pressure and since they are accurately coordinated it follows that the control will act to maintain the same air flow through all venturi nozzles of a zone. A change in boiler output is effected through a change in plenum chamber pressure effected manually as described below.

A change in speed of the blower or induced-draft fan or in the position of their dampers, will produce a corresponding change in plenum-chamber pressure. An increased pressure will produce an increased differential impulse from the master venturi nozzle to the master controller, which in turn will increase the loading pressure going to the zone regulators. This loading pressure, being common to all six zone regulators and supplementary to the spring tension on the diaphragm of these regulators, automatically increases the loading pressure on all of the 72 air-flow regulators and thus produces a change in adjustment of the dampers in the 72 metering boxes. This tends to change the differential across each

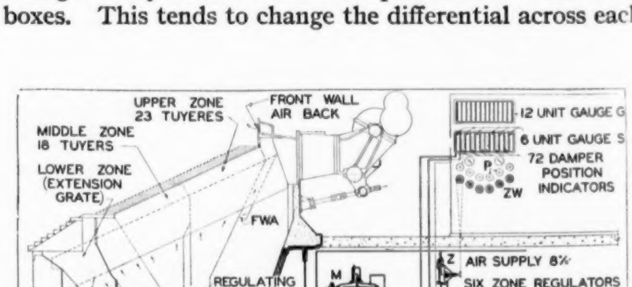

Fig. 17—Diagram of Conners Creek air control

of the venturis so as to balance the increased pressure on the 72 loading-pressure diaphragms. The net effect is that an increase in plenum-chamber pressure produces a simultaneous increase in air flow through all 72 metering boxes, while a decrease in plenum chamber pressure produces a similar reduction in air flow.

No manual adjustment of the regulators is necessary on account of load changes so long as no change in the relative air flow in the different zones is desired. A change in the bias of air flows between the different zones must be accomplished through adjusting the spring tension of the zone regulators by manually turning their handwheels mounted on the boiler-gage board.

Design Changes Found Necessary in Operation

The combustion air control as installed on boilers Nos. 1 and 2 is performing very satisfactorily. As in all new developments, possible improvements appear with experience, but, considering that this type of air control is practically in its infancy, remarkably few changes were necessary for the additional units under the more recently installed boilers.

False Front Wall: Some minor alterations in the apparatus and some re-arrangement of the equipment were made when boilers Nos. 3 and 4 were erected. Through introducing a false front wall, certain parts were relocated with respect to the plenum chamber, thus increasing their accessibility for maintenance and shielding the regulators from severe temperature. The false wall also permitted that part of the damper-operating rod which enters the power cylinder to be kept outside the plenum chamber. This change was necessary because, in the original installations, dust carried to the plenum-chamber seal caused scoring of the rod with consequent water leakage from the cylinder. Incidental to the change is the possibility of complete removal and replacement of the power cylinder if necessary during boiler operation.

Damper Position Indicator: That some type of indicating device to show the positions of the control dampers would be helpful became quite evident after boilers Nos. 1 and 2 were placed in operation. Extensive experiments were made on No. 1 boiler to develop and compare mechanical and electrical indicators. The final choice was an electrical arrangement consisting of a resistance coil and sliding contact actuated by the power-cylinder rod and supplied with low-voltage ac current, and an indicating instrument on the gage board to show the operator the damper position. This device was installed at the time of erection on Nos. 3 and 4 boilers, and later, on the first two boilers.

Despite evidence of some need for small changes in the stoker and combustion-air control at Conners Creek, the Company's engineers and operators are enthused with the satisfactory performance of the equipment and feel that the time and money given to development of both have been well spent. Experience in different plants has shown zoned air control to be equally satisfactory either with or without preheated air, and of value both through raising the efficiency of the combustion unit and increasing its sustained output. The demonstrated advantages of the improved automatic type of control used at Conners Creek has led to a decision to replace the earlier air control used at Delray with the Conners Creek design.

Charles W. E. Clarke has opened an office as consulting engineer at 12 S. Twelfth Street, Philadelphia, Pa. Mr. Clarke was formerly with United Engineers & Constructors, Inc.

L. G. Haller has been appointed Chief Engineer of the Tennessee Eastman Corporation, Kingsport, Tenn., in which capacity he will have charge of all engineering pertaining to equipment and plant layout. Mr. Haller was formerly manager of the Chattanooga office of Combustion Engineering Company Inc.

Frank S. Scott, formerly of the fuel engineering staff of Appalachian Coals, Inc., has joined the new River Coal Company, Charleston, W. Va., to direct its fuel engineering service. Previous connections of Mr. Scott were in combustion work with the U. S. Rubber Company, General Motors Corporation and The Detroit Edison Company.

John Primrose, who has been Vice-President of the Foster Wheeler Corporation since it was organized, has been elected to the office of Vice Chairman of the Board, following the resignation of P. W. Foster, who will continue as a director.

H. B. Meller of Pittsburgh, well-known authority on smoke abatement and atmospheric pollution, has been appointed managing director of the Air Hygiene Foundation of America which has been formed by a group of industries to conduct investigations and to stimulate research in the field of atmospheric contamination.

R. A. Langworthy has joined the Harry M. Hope Engineering Company, 420 Lexington Avenue, New York, as Executive Vice-President. Previous to his present connection Mr. Langworthy was for a number of years with United Engineers & Constructors, Inc.

Henry W. Foulds has been elected Vice-President of The Permutit Company, New York, in which capacity he will correlate and direct sales, promotion and advertising.

The consulting engineering firm of **Baker & Spencer** which a few years back was identified with much important engineering work, particularly in the industrial power plant field, has again become active with offices at 17 Battery Place, New York. Mr. Baker died several years ago and **H. D. Savage,** formerly an executive of Combustion Engineering Corporation, is now associated with **C. G. Spencer** under the original firm name.

Burning Appalachian Coals in Pulverized Form*

By HENRY KREISINGER
Combustion Engineering Company, Inc.

The paper discusses the effects of volatile content, fineness of grinding, moisture and preheat on the ignition of pulverized coal; also factors that insure proper mixing of the fuel particles with the combustion air. These points are considered both basically and with special reference to coals from the Appalachian region.

COALS of the Appalachian fields vary in chemical and physical properties that affect their burning in pulverized form. The volatile matter varies from about 14 to 46 per cent of the total combustible in the coal and the hardness varies from the hard coals of the Pittsburgh region to the very soft coals of the Pocahontas and New River type. The Appalachian field supplies about 75 per cent of the coal used in the United States and only about 10 per cent is burned in pulverized form.

The percentage of volatile matter affects the burning and the hardness affects pulverization. Generally speaking, coals of low volatile content are granular in structure, are soft and are easy to pulverize but more difficult to burn, whereas those with high volatile content are hard and therefore difficult to pulverize, but because of their high volatile content they burn more easily.

Effect of Volatile Matter on Ignition

Volatile content affects the ignition and stability of the flame. The ignition temperature of the gases driven off as volatile matter is about 1100 F and that of fixed carbon is about 1800 F. Therefore, the ignition temperature of a coal is the ignition temperature of the gases driven off as volatile matter.

Pulverized coal is supplied to the furnace suspended in primary air which supplies the oxygen needed for ignition. The coal upon entering the furnace is quickly heated to a point at which a large part of the volatile matter is distilled off as gas. The heat required to distill the volatile matter and to raise the temperature of the mixture of the distilled gases and the primary air to the ignition point is supplied mostly by radiation from the already burning coal farther away from the burner. The primary air and the distilled gases form the ignition mixture. When this contains a large proportion of combustible gases it ignites quickly and the flame in the ignition zone is stable. If, on the other hand, the percentage of combustible gases in the ignition mixture is low, the ignition is slow and the flame is unstable, pulsating back and forth some distance from the burner. In other words, when the ignition mixture is rich the ignition is quick and the flame is stable; when the mixture is lean the ignition is slow and the flame is unstable. With the same density of mixture of coal and primary air, the ignition mixture is rich with coals containing high percentages of volatile matter and it is likely to be lean with coals containing low percentages of volatile matter. Consequently, the ignition is quick and the flame stable with high volatile coal, and the ignition is apt to be slow and the flame unstable with coals having low volatile matter content. This is particularly the case when fires are started under a cold boiler.

Lighting Fire under Cold Boiler

When we start an automobile engine on a cold day we pull the choke out thereby reducing the air supply and making the mixture of gasoline and air rich. In a similar way when we start a pulverized coal furnace under a cold boiler we start the fires with a rich mixture of pulverized coal and air. We reduce the draft in the furnace, and if the air is supplied to the furnace under pressure, we reduce this air pressure to a minimum. If the coal has a low volatile content we reduce the amount of primary air and admit the secondary air beyond the ignition zone. The heat required to distill the gas from the coal and to raise the ignition mixture to the ignition temperature is supplied by the lighting torch. The ignition of the coal mixture starts at the flame of the lighting torch and if the mixture is rich the ignition spreads over the entire coal stream.

Delayed Admission of Secondary Air

The admission of secondary air beyond the ignition zone is a problem of burner and furnace design. It is well known that the burning equipment for low volatile fuels, such as anthracite and pulverized coke breeze, is different from that designed to burn high volatile coal. The best success with such fuels is obtained by firing them through an arch vertically downward and supplying the secondary air through air ports in the front wall at the right distance from the burner after ignition has taken place. On the other hand, high volatile coals are, in many cases, fired horizontally with practically all of the secondary air supplied around the burner nozzle. If delayed mixing of the secondary air with the ignition mixture is needed, it is obtained by enlarging the throat of the burner so that the secondary air may enter the furnace in a hollow cone without immediately mixing with the stream of primary air and coal.

* From a talk before the engineers of Appalachian Coals, Inc., October 29.

Effects of Fineness, Moisture and Preheat

Ignition mixture can be made richer by fine pulverization. The small particles of fuel are more easily kept in suspension and therefore the primary air can be greatly reduced. The reduction of primary air and the greater surface of the finer coal particles, causes them to be quickly heated to the temperature at which most of the volatile is distilled off.

Another factor in the formation of rich ignition mixture is the dryness of the coal. Moisture in coal must be evaporated before any combustible gases can be distilled off.

If the fuel contains a high percentage of moisture the evaporation of this moisture delays the heating of the fuel particles. More time is taken to distill enough of the combustible gases to make the mixture with primary air sufficiently rich for ignition. Therefore, coals having a low percentage of volatile should also be low in moisture if they are to be burned successfully in pulverized form.

Preheating the primary air also helps to make the ignition mixture richer. Less additional heat is needed to distill enough of the volatile matter in the coal and to bring the mixture to the ignition temperature. The time required to accomplish this heating is shorter and the ignition is quicker.

Completeness of Combustion

It has been stated that ignition is slow with low volatile coals. Slow ignition causes delayed combustion which, in turn, results in less complete combustion. With a given size of furnace and gas mixing devices, high volatile coals burn more completely than those of low volatile content. During the first part of the combustion process the volatile is distilled and diffuses into the air surrounding the coal particles. The combustible gas is in molecular subdivision, the individual molecules being free to move in the space and find the oxygen molecules easily. On the other hand, the fixed carbon exists as a mass of molecules which cannot move freely. Thus, the combustible gas makes contact with the free oxygen much more readily than the fixed carbon in the coal particles. It may be said that the distilled volatile matter goes halfway to make contact with the oxygen, whereas the fixed carbon waits until oxygen comes to it.

Effect of Mixing on Combustion

Contact between the fuel particles and the oxygen molecule is greatly facilitated by relative motion between the former and the furnace gases containing the free oxygen. A furnace in which the mixing extends throughout the entire combustion space is more effective in burning fixed carbon than one in which the mixing is limited to the comparatively small space around the burners. It is the last stage of the combustion process which is slow, because there are comparatively few small particles containing unburned carbon and few oxygen molecules with which the carbon can make contact and combine. Usually the last stage of combustion takes place with the furnace gases containing only 1 to 3 per cent of free oxygen. If the mixing does not extend throughout the entire furnace the free oxygen may be in one part of the furnace and the particles of fuel containing unconsumed carbon in another part, and some of the fuel particles may leave the furnace unburned.

It is difficult to supply fuel to the furnace as a uniform mixture of coal and air. The tendency for coal to settle out causes some part of the stream to contain more coal than other parts, and this coal concentration changes continually. As a result of this difference those parts having greater concentration of coal will distill more or denser combustible gas, while those parts of the stream having light concentration will have less combustible gas and more air than is needed for complete combustion. Intensive mixing will equalize the percentage of combustible gas and free oxygen across the entire section of the stream of burning mixture.

Effect of Length of Flame Path on Mixing

Mixing of unburned particles of coal and combustible gas with oxygen can be accomplished better if the path of the burning mixture is long and small in cross-section. The burning mixture in such cases has to move through the combustion space at higher speed, produces eddies in the stream thus equalizing the mixture and making its composition uniform. Short flame path through the combustion space and a slow moving stream of large cross-section is undesirable.

A method of firing pulverized coal which produces the most intensive mixing in the furnace is the tangential arrangement. With this the mixture of coal and air is supplied to the furnace through four sets of burners, one in each corner of a nearly square furnace. The four streams of burning mixture are directed into the furnace in such a way that they are tangent to a circle whose center is in the center of the furnace. This direction of the streams produces a rotative motion in the burning mixture and fills the furnace completely, thus making all the combustion space fully effective. The burning mixture moves through the furnace in a helical path with considerable eddying in the corners. The mixing is intensive and more complete combustion can be obtained than with other methods of firing.

Because of the intensive mixing and the impingement of the burning mixture against the furnace walls, the tangential method of firing can be used only with completely water-cooled furnaces. With this intensive mixing the combustion is very rapid and the heat liberation in the *burner zone* is very high—of the order of 100,000 Btu per cu ft per hr.

Another arrangement is opposed firing in which there are two sets of burners, one set in each side wall. The streams from the opposite burners meet in the middle of the furnace and produce an intensive mixing.

One of the reasons why pulverized fuel firing is favored in many cases is the fact that a properly designed pulverized coal furnace is well adapted to burning a variety of coals, also to burning fuel oil and gaseous fuels such as natural gas, blast-furnace gas and coke-oven gas. In some of the installations coal or oil is burned alternately whichever of the two fuels happens to be cheaper at the time. The change from one fuel to the other can be made on one burner at a time so that the furnace can be entirely changed over without reduction of load.

Moisture and Ash as They Affect Pulverization

Coals from the Appalachian field normally have low moisture content, hence do not present much of a drying problem. Such drying as is needed can be accomplished by supplying the mill with heated air. Even washed coal may not contain too much moisture for mill drying, pro-

vided the coal does not contain too much fines holding excessive moisture. Wet fines are objectionable also because they make the coal stick in conveyors, chutes, mill feeders and other coal handling apparatus. Excessive fines in coal not only increase the cost of handling but also make coal supply and coal feeding unreliable. Interruption of coal feed to the mill may cause the fires to go out which, in turn, means the loss of load. The effect of moisture on the ignition of coal has already been discussed. Excess moisture causes slow ignition which, in turn, causes delayed combustion and results in incomplete combustion.

Ash increases the cost of pulverization and the outage of the mill. In this respect pulverized coal is not like stokers where very low ash coal is generally objectionable because some of the stoker parts are likely to become exposed to high temperature with resulting high stoker maintenance. With pulverized coal the lower the ash content the more desirable the coal.

Fusibility of Ash and Furnace Design and Operation

Fusibility of the ash affects the burning of coal to a small extent. For very fusible ash coals the furnace can be designed for discharging the ash in molten form, although slagging of the boiler tubes and superheater may become a problem. The ash carried by the gases may still be in plastic condition when it reaches the boiler and superheater and be plastered on their surfaces. The higher the pressure and temperature of the steam, the more the ash is likely to stick and slag up these surfaces. Water-cooled furnaces with large combustion space and long flame path are well suited to burning coals with low fusing ash. The furnace gases give up heat to the furnace walls and boiler by radiation, and with long flame travel the ash particles carried by the gases are cooler when they reach the boiler, hence stick less to the surfaces.

One drawback to such an arrangement is that with the demand for high steam temperature the surface of the superheater must be large and therefore expensive. It is part of the price one has to pay to enable him to burn coal with fusible ash.

Corrosion of Iron in the Presence of and in the Absence of Oxygen

A Discussion

In the June issue of COMBUSTION, the article "The Extent of Corrosion of Iron in the Presence of and the Absence of Oxygen," contained a few errors which the author desires to correct. These were brought to the attention of the author by E. W. Guernsey, Assistant Director of Research of the Consolidated Gas Electric Light and Power Co. of Baltimore. To quote Mr. Guernsey:

"In the first place, there is an error in the conclusion that an acid solution can be procured by the simultaneous action of oxygen and water on iron. This will be apparent from the simple consideration that since positive and negative ions in the solution must be in electrical balance, as represented by the equation

$$[H^+] + 3\,[Fe^{+++}] = [OH^-] \qquad (I)$$

the concentration of the hydroxyl ion, $[OH^-]$, must be greater than the hydrogen-ion concentration $[H^+]$. It was incorrectly assumed, that in the system iron–oxygen–water, the hydroxyl ion concentration, when the water is saturated with ferric hydroxide, is equal to three times the concentration of ferric ions. The fact is that an important fraction of the hydroxyl ions are balanced by hydrogen ions instead of by ferric ions.

"If one wishes to calculate the pH of the solution, assuming that in the presence of oxygen there are no ferrous ions, these being instantaneously oxidized to ferric ions, then it can be done by solving three simultaneous equations. Equation (I) above is the first of these, and the other two follow:

$$[Fe^{+++}] \times [OH^-] = 1.1 \times 10^{-36} \qquad (II)$$ Solubility Product of ferric oxide.

$$[H^+] \times [OH^-] = 10^{-14} \qquad (III)$$ Ionization constant of water.

It is found in this way that the hydrogen-ion concentration, H^+, is very slightly less than 10^{-7} and the solution is practically neutral."

Mr. Guernsey is correct. The author's diagram in the original paper should be corrected to consider the variation of the pH of the water in contact with iron and oxygen to vary at their possible extremes from 9.6 in the complete absence of oxygen, to 7 in the presence of unlimited oxygen. Mr. Guernsey continues:

"At other points in the paper it seems to be implied that when, in the absence of oxygen, the solution becomes saturated with ferrous iron, corrosion becomes impossible because the driving force is zero, or as was expressed, 'solution pressure was balanced by osmotic pressure.'" The implication is that when the solution was saturated with ferrous hydroxide there existed the necessary amount of ferrous ion which exerted an osmotic pressure equal to the solution pressure of the iron. In fact, the necessary amount of iron needed as ferrous ion to stop the corrosion of iron if no protective film existed is of the order of 10^{-3} mols per liter, according to Mr. Guernsey's calculation. He continues:

"There is no doubt that, under favorable circumstances, the corrosion of iron by water in the absence of oxygen may be reduced or practically eliminated when the solution becomes saturated with ferrous ions, but this is not due primarily to a reduction of driving force, but rather to the formation of an effective protective film of ferrous hydroxide (or more stable oxides formed from it), as soon as the solution becomes saturated with ferrous hydroxide. Under any conditions preventing the formation of an effective protective film, corrosion can continue even though the solution is saturated with ferrous hydroxide."

The author did not mean to convey the notion that when the iron corrodes until the pH value of the water reaches 9.6, there is sufficient ferrous ion in solution to exert the necessary osmotic pressure which balances the inherent solution pressure of iron. What he meant was to point out the fallacy of assuming that, because the pH value of water in a saturated solution of ferrous hydroxide after corrosion has ceased in the absence of oxygen is 9.6, all that is necessary is to add sodium hydroxide until the pH is 9.6 and then forget the influence of oxygen. One must remember that the antecedent of the high pH was the dissolution of the iron—enough iron to constitute a protective film against further dissolution.

As a protective film is not possible unless the solution becomes saturated with ferrous hydroxide, and, since the solution will never become saturated with ferrous hydroxide and attain the pH of 9.6 in the presence of oxygen, it follows that oxygen is the substance to keep at the absolute minimum. Two mols of ferrous ion are eliminated by one atom of oxygen. If the ferrous ion is not in solution, then the oxygen will attack the ferrous ion that is a part of the protective film. In other words, a protective film can hardly be realized with oxygen present. In short, with oxygen present, that condition will obtain which brings into play the maximum solution pressure of iron and the least osmotic pressure of ferrous ions.

The author wishes to thank Mr. Guernsey for his interest in clarifying the subject matter in the paper.

SALVATORE ALFANO

Cause and Prevention of Turbine-Blade Deposits*

By FREDERICK G. STRAUB
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A survey was made of power plants encountering turbine-blade deposits and it was found that this trouble results from contamination of the steam by the boiler water. A study in the laboratory showed that sodium hydroxide is the material which causes the sticking to the blades. It was also shown that when the sodium hydroxide is neutralized and changed to a salt such as sodium carbonate, it will not adhere. The presence of sufficient amounts of inert salts, such as sodium sulphate, with the sodium hydroxide also will stop the deposit from forming.

The action of sodium sulphate in preventing the blade deposits was studied in a large central power plant, and the deposit was materially reduced. A small testing unit for detecting the presence of adhering salts in the steam was developed and used in the power-plant tests.

STEAM-electrical generating stations have encountered difficulty in the form of fouling of turbine blades. This difficulty has become of major importance in many large stations whereas it has only meant annoyance in other stations.

There are several types of deposits which form on the turbine blading and cause this fouling. One is that which is apparently caused by a deposition of solids carried in the steam from the boiler water and another is that caused by a chemical reaction between chemicals in the steam and the material in the turbine blade. The first type is most common and is readily distinguished because it is largely water-soluble and is washed off with comparative ease, whereas the other type adheres tenaciously to the blades.

The difficulty caused by the deposition of solids carried in the steam appears to be the one causing the major difficulty. The efforts of this research have been expended entirely toward the study of this type of deposit and no study has been made of the other type.

A survey was made of power plants encountering this trouble as well as those not having difficulty with blade deposits.

The summary of conclusions reached after assembling the available data in regard to turbine-blade deposits is as follows:

1. The deposits formed independent of steam pressure or temperature.
2. The deposits were not proportional to the total concentration of solids in the boiler water.
3. The total solids in the steam were very low in many plants where deposits occurred.
4. The deposits all contained sodium present as hydroxide, carbonate or silicate.
5. The deposits were practically all water-soluble.

Laboratory Experiments

The deposits which were formed in the plants under consideration all originated in the boiler water. A small amount of the boiler water may be easily carried into the steam. Actually, this amount does not have to be more than one-tenth of one per cent of moisture in the steam to cause appreciable trouble at the turbine. Thus if a boiler water should contain about 300 ppm total solids, which is a rather low concentration, and one-tenth of one per cent of the steam were present as boiler water, the steam would contain 0.3 ppm of total solids. This appears a negligible amount; but with a turbine using one million pounds of steam per hour, 8 lb of solids would pass through the turbine in 24 hr. If only 10 per cent of this were to adhere to the turbine blades, the efficiency and capacity loss would increase at an alarming rate.

In order to determine whether there is present in the average boiler water material which would cause adherence or sticking to the turbine blade a study was made of the behavior of the various salts encountered in boiler waters as they pass from solution in wet steam to superheated steam. If only pure water were present in the boiler and a small amount of the boiler water were mechanically carried into the steam and to the superheater, the droplets of water would vaporize in the superheater and no free moisture would be present in the superheated steam. However, if sodium chloride, sodium carbonate or sodium sulphate were present in the boiler water the droplet of water entering the superheater with the steam would contain a dilute solution of the salt or salts. As the steam became superheated the water would vaporize and leave a dry salt or powder of the salt or salts with the superheated steam. Consequently, they would pass through the steam pipes and turbine as a fine powder or dust and cause no appreciable difficulty. This is based on the assumption that there is only a small percentage of moisture in the steam. However, if sodium hydroxide were present this would not happen. This results from the fact that the behavior of sodium hydroxide solutions is entirely different from that of the other salts discussed.

*From a paper presented at the Power Session, Annual Meeting of the American Society of Mechanical Engineers, New York, Dec. 2-6, 1935. Part of the research was conducted in cooperation with the Utilities Research Commission, Chicago, Ill. and is published by permission of Dean M. L. Enger, Director, Engineering Experiment Station, University of Illinois.

When a solution of sodium chloride, carbonate or sulphate is boiled, the solution is concentrated as the steam is released and the solution concentrates until a saturated solution is obtained. Any further release of steam results in the precipitation of the salt. Eventually, if the boiling is continued, all the water is evaporated and dry salt or salts are left behind. If a solution of sodium hydroxide is boiled, the solution concentrates with a continual increase in temperature until a concentration is reached where the concentrated solution is in equilibrium with the vapor pressure of the surrounding atmosphere and further heating will cause a release of steam to the surrounding atmosphere with an increase in concentration of the caustic solution and an increase in the temperature of the solution.

If a drop of water containing sodium hydroxide in solution leaves a boiler at a pressure of 600 lb per sq in. abs and enters the superheater with the steam, the water will vaporize, thus concentrating the solution. When the temperature of the steam reaches 600 F the concentration of the caustic will represent about a 60 per cent solution. If the temperature and pressure remained constant, the droplet of caustic would remain 60 per cent sodium hydroxide and 40 per cent moisture, even in contact with superheated steam. As the temperature increases, the pressure remaining constant, the caustic concentration will increase. At a pressure of 600 lb and a temperature of 700 F, the concentration would be as shown at point *B*, an 80 per cent solution.

The concentration of caustic in equilibrium with superheated steam at various pressures and temperatures is shown in Fig. 1. This shows that the concentrations of sodium hydroxide reached in the average higher pressure plant is between 80 and 90 per cent. A solution of sodium hydroxide containing between 10 and 20 per cent moisture at these temperatures will be in a pasty or semi-fluid state and in going through the turbine will adhere to the blades. The other salts, present as a fine dust, will adhere with the sodium hydroxide, but not necessarily in the relative proportions in which they exist in the boiler water. When the temperature of the steam in the turbine is lowered until saturated steam exists, these salts will be dissolved and thus wash off of the blades. The experience which turbine operators have had with washing of turbines confirms this.

In order to substantiate this theory tests were run in the laboratory. The procedure followed in these tests was to produce steam in a small electrically heated boiler, contaminate the steam with a solution of a desired salt or combination of salts, superheat the contaminated steam, pass the steam through an orifice so that it impinged on a stationary blade and then condense the steam at a predetermined pressure.

The first tests were run for 22 hr with 2 grams sodium hydroxide added to the contaminator and the temperature of the superheated steam varied between 400 and 700 F. Deposits formed on the blade. The theoretical composition of the sodium hydroxide in the steam at the time of contact with the blade during these tests varied from about 85 per cent at 400 F to about 98 per cent at 700 F. Tests run with distilled water alone in the contaminator gave a clean blade. When sodium chloride was added to the contaminator and tests run at 500 F, no deposit formed on the blade in the area of high velocity. Similar tests with sodium sulphate gave like results.

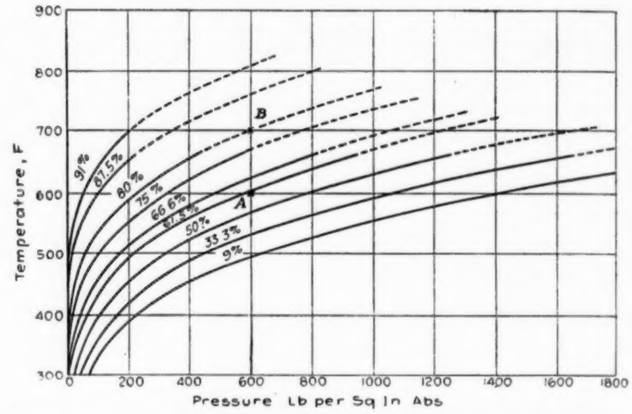


Fig. 1—Concentration of NaOH in relation to steam pressure and temperature

Trisodium phosphate and sodium silicate both formed deposits on the blade.

The sodium hydroxide, silicate and phosphate deposits were formed because hydroxide was present in all these salts. If this is true, any chemical added to the contaminated steam which would neutralize the hydroxide should prevent the hydroxide from forming. In order to prove this hypothesis the apparatus was modified so that carbon dioxide could be slowly added to the steam beyond the contaminator and ahead of the superheater. The carbon dioxide, if present in excess, should react with the hydroxide to form sodium carbonate. This salt should exist as a dry powder in the steam and no deposit should form. When carbon dioxide was added after contamination with sodium hydroxide, sodium silicate and sodium phosphate, no deposits formed. This showed conclusively that the sodium hydroxide was the binding or adhering agent, and if it were changed to carbonate prior to reaching the blade, no deposit would form.

In order to study the possibility of the utilization of carbon dioxide treatment the apparatus was modified so that the carbon dioxide could be added to the superheated steam instead of the wet steam. When tests were run using this method of treatment the deposits continued to form even when large excesses of carbon dioxide were present.

This change in the action of the carbon dioxide is easily explained. When the gas is added to the wet steam the sodium hydroxide in the droplets of water is in a dilute solution. In this state the carbon dioxide also is soluble in the water depending upon its partial pressure in the steam. As the two chemicals are in dilute solutions, they are strongly ionized and will react readily so that the sodium carbonate is formed before the steam is superheated. However, when the steam is superheated before adding the carbon dioxide the excess water present is converted to steam and the sodium hydroxide is present in the form of a highly concentrated solution, more than 80 per cent NaOH. In such a solution the hydroxide is only slightly ionized, the carbon dioxide is present in the steam as a dry gas, consequently there is practically no reaction between the gas and the sodium hydroxide. This appeared to make the carbon dioxide method of treatment rather complicated.

Concentration of Caustic Necessary for Deposit

After this substantiation of the hypothesis that sodium hydroxide is the basic adhering material in the turbine-

blade deposits it seemed desirable to obtain further data on the limiting concentration of sodium hydroxide in the steam which would cause blade deposition and on other methods of prevention of this troublesome deposit.

In the apparatus already mentioned the carry-over or contamination of the steam was excessive in the early period of the test. This was shown by the fact that with a constant water level in the contaminator the concentration of the contaminating salts steadily decreased. At the same time it was almost impossible to know the amount of contamination in the steam at any particular time. In order to overcome these objections the apparatus was redesigned so as to make possible determination of the amount of contamination.

Tests were then run using the new apparatus and holding the vacuum in the blade chamber at 20 in. of mercury. With the sodium hydroxide in the steam (calculated) at 48, 18, 5, 2 and 1.5 ppm deposits formed in 20-hr tests. Tests in which distilled water was added to the steam gave no deposit. When the steam was passed through the nozzle there was a marked change in velocity. The calculated velocity in the steam line ahead of the nozzle was 21.5 fps. The velocity through the nozzle was 1175 fps and the velocity past the blade was 950 fps. Thus the velocity at point of contact with the blade was approximately 1000 fps.

The maintenance of a vacuum in the blade holder complicated the operation of the test. Consequently, tests were run in which atmospheric pressure was maintained in the blade holder. With such a change in conditions the velocity of the steam in the holder dropped from a nozzle velocity of 1175 fps to 320 fps. Undoubtedly the velocity at the point of impact with the blade was still in the range of 1000 fps. Tests run under these conditions with 4, 5, 4.0, 3.2 and 2 ppm of sodium hydroxide added to the steam gave deposits in the 20-hr tests. This showed that a deposit would form with the sodium hydroxide content of 2 ppm in 20 hr. The remainder of the tests were run at this pressure unless otherwise noted.

Sodium sulphate alone was added so as to have 10 ppm in the steam and no deposit formed. A mixture of sodium hydroxide and sulphate was then added so that the NaOH was 4.2 and the Na_2SO_4 8.6 ppm in the steam and small deposits formed, but not as much as that formed by the sodium hydroxide in the absence of the sodium sulphate. The sodium hydroxide was then increased to 5.8 and the sulphate to 25 ppm and no deposit formed. This test was followed by one with a sodium hydroxide concentration of 2.9 ppm and no sulphate. A definite deposit formed. This appeared to indicate that the sulphate was preventing the hydroxide from adhering to the blade.

Tests were then run with the sodium hydroxide concentration held constant at 3 ppm and the temperature at 350, 400 and 615 F. A deposit formed in all these tests, indicating that changing the temperature did not have much effect upon the tendency of the sodium hydroxide to adhere to the blade.

Prevention of Deposit

Tests were run with varying amounts of sodium sulphate when the sodium hydroxide content was constant. When the ratio of the sodium sulphate to the sodium hydroxide was 4.4 and greater the deposit did not form. This checked with the previous results and indicated that the presence of a sufficient amount of sodium sulphate with the sodium hydroxide prevents the formation of a deposit on the blade.

The addition of sodium chloride to the sodium sulphate so that the ratio of sodium sulphate to sodium hydroxide was 3.3 and sodium chloride to sodium hydroxide was 2.5, or the ratio of the total of the sodium sulphate and chloride to the sodium hydroxide was 5.8, did not entirely prevent the deposit. However, the deposit was less than it would have been with the sulphate alone present with the hydroxide, indicating that sodium chloride when present with the sulphate aids in the prevention of the deposit.

The presence of silicate along with the hydroxide tended to decrease formation of the deposit. When the sodium sulphate was present in an amount four times the sodium hydroxide, only a small deposit formed. This indicated that the sulphate was also effective in the presence of the silicate.

Effect of Contaminating Steam with Boiler Water

In the tests previously run the contamination was accomplished by adding the desired chemicals to the steam. This showed that if these chemicals were present in the steam the deposits could be formed or prevented. However, it seemed advisable to determine the actual ratios of the inhibiting chemicals necessary in the boiler water to prevent deposits. In such tests the contamination of the steam would result entirely from carry-over from the boiler and the results would be more readily applied to actual operation.

These tests were run for $5^1/_2$ hr at a steam pressure of 600 lb per sq in. and a total steam temperature of 700 F. The orifice was changed to a round hole, No. 75 drill, instead of a slot. The pressure in the blade holder was changed from atmospheric to 500 lb per sq in. gage, thus giving a pressure drop of 100 lb across the nozzle. The amount of steam passing through the nozzle per hour was the same as in the previous lower pressure tests.

When these tests were started the blades were found to be coated with a film of what appeared to be magnetic oxide. This coating formed all over the blades and appeared to be the result of a reaction between the superheated steam and the steel in the blades. When the pressure was dropped to 300 lb and the temperature to 500 F, this action stopped. Stainless-steel blades, 18 chromium, 8 nickel, were substituted for the steel blades. When the steam was of high quality and apparently contained no sodium hydroxide, the blade remained clean and was not attacked by the steam. When the boiler water contained sodium hydroxide the blades were attacked and became so brittle that they broke upon being removed. Substitution of monel metal blades appeared to overcome these difficulties and a series of tests was run with this type of blade.

Plant Experiments

The results reported from many power plants indicate that the detection of the difficulty encountered with blade deposits is mainly in the form of loss of capacity. The efficiency loss becomes appreciable before capacity loss is detected. When capacity loss is noticed the deposits have formed, and they must be removed to obtain normal operation. Thus, if the water treatment is to be

studied or modified to prevent the deposits from forming, it is advisable to have a rapid method of studying the effect on the formation or prevention of deposits. Early in the research, attempts were made to devise a small testing unit which could be used to test samples of the steam in an operating plant and tell in a relatively short period of testing whether the steam would cause blade deposits or not. If such a unit could be devised, a definite study could be made on the effect of modification of water treatment on the deposits formed without waiting for the effect to be noticeable at the turbine.

A small test unit was made which would allow a small amount of the steam from the heater just ahead of the turbine to flow through a nozzle, strike a section of regular turbine blades, and then exhaust through a regulating valve. With data relative to the temperature, pressure and size of nozzle available, the velocity of the steam passing the blades and the quantity per unit of time could be calculated. The blades could be removed at any time desired and the amount of deposit formed could be determined by weighing.

The unit was tested in a central plant operating at a pressure of 600 lb per sq in. and a steam temperature of 725 F. The steam pressure at the nozzle was between 350 and 520 lb per sq in. and the temperature between 635 and 725 F. The pressure drop through the unit was adjusted so as to obtain the desired rate of flow. This was held at 870 lb per hr in the majority of tests and was accomplished with a pressure drop of 100 lb. With this pressure drop the velocity of the steam passing the blades was about 460 fps.

The unit was installed on a line connected to the steam header just ahead of the turbine. The first test was run for 53 hr and gave a total deposit of 11.3 mg or at the rate of 251 mg per million pounds of steam. The next test was run under the same conditions for 234 hr and the amount of deposit was 45.5 mg and the rate of deposit was 221 mg per million pounds of steam. This indicated that the rate was almost constant and a test of 52 hr was sufficient to detect the amount of deposit forming.

In the next test the rate of flow was lowered from 870 to 430 lb per hr, which changed the velocity from 460 to 140 fps. The deposit increased, forming at a rate of 310 mg per million pounds of steam. This third test showed that the deposit would form over a wide range of steam flow through the unit. During these tests the regular water treatment was in use and the plant was experiencing difficulty with blade deposits. The turbine was washed every four weeks.

The boiler-water treatment was modified early in October 1934, to increase the sulphate concentrations so that they would be similar to those found advisable in the laboratory tests. In order to obtain the desired sulphate, sodium sulphite was added. The sulphite would react with the small amount of oxygen present and reduce corrosion. The sulphate formed would aid in the prevention of blade deposits.

The sodium sulphate content before the addition of the sulphite was between 15 and 30 ppm. At the time of change in water treatment the sodium hydroxide content was also increased with a corresponding change in pH value. All of these changes increased the total dissolved solids in the boiler water from a maximum of 260 ppm to about 1200 ppm. The ratio of the sodium sulphate to total alkalinity increased to a range between 3.5 and 4.6 for the period between October 1 and November 11.

The turbine was washed on July 22 and not washed until Sept. 2, a duration of six weeks instead of four weeks as usual. The loss due to blade deposits, calculated from increase in stage pressure over that of a clean turbine, was greater at the end of these six weeks than for a regular four-week period, as was to be expected. The water treatment was changed about October 1, a period of four weeks after the turbine had been washed. At this time the tests of the turbine showed about the regular amount of loss due to deposits. The turbine was not washed. The deposit did not appear to increase as rapidly as before the changes in water treatment and the turbine was allowed to run until November 11 before washing. The deposit did not appear to be causing any more difficulty at the end of the ten weeks than at the end of the first four weeks.

Tests run on the small testing unit during the period after change in water treatment showed a deposit rate of between 20 and 66 mg per million pounds of steam as compared to 250 mg per million pounds of steam prior to the change, a reduction of about 90 per cent in the deposit. The amounts of deposits weighed were about 0.5 mg which was about the limit of accuracy of weighing. These results appeared to indicate that the deposit was being materially reduced.

The turbine was not washed again until February 3, 1935, a duration of twelve weeks. During this period the sodium sulphate to total alkalinity ratio dropped from 3.5 to 1.6 and was 2.5 at the time of washing. The turbine was taken out of service on March 24, for overhauling and inspection, and was washed to aid in cooling. When opened it was found free from deposits, indicating that if any were forming they were all removed by washing.

While the turbine was out of service the method of adding the sodium sulphite was changed from intermittent dosage to a continuous feed. It was hoped that this would give a better control of chemical feed and thus show a more consistent sulphate concentration. However, the sulphite was added at a point where appreciable oxygen was present, ahead of the heaters, and this brought about an increase in the sulphate formed. The sulphate content increased to a much higher value than was previously maintained.

When the turbine went back into service blade-deposit formation appeared to be slow. It was not washed again until July 14, a duration of 14 weeks. Thus, the time of washing was changed from four-week periods prior to the change in water treatment to an average of 12 weeks; and this change resulted during the period when the control of the water treatment was in the experimental stage.

Discussion of Results

The results of these studies indicate that the turbine-blade fouling is caused by chemicals carried into the steam from the boiler water. The amount of this contamination does not have to be large and steam which would normally be referred to as being of excellent quality might cause a great amount of deposit. The chemical causing the major portion of the difficulty appears to be sodium hydroxide. This is present in practically all boiler waters and when carried with steam that is

superheated forms a concentrated sticky solution. This sticky material forms the basic binder and adheres to the turbine blades. Other salts present in the form of a dry powder would normally be swept past the blades. However, when caustic soda is present these salts adhere with the pasty caustic. This may cause a deposit in which the relative proportions of the constituents bear no relationship to the ratios in which they occur in the boiler water.

Deposits May Form Even with Low Concentrations of Sodium Hydroxide

The amount of deposit is not proportional to the carry over from the boiler, but depends upon the relationship which exists between the various salts in the boiler water. Thus, high hydroxide in respect to the total solids may cause an excessive deposition even with a low concentration of sodium hydroxide in the boiler water. However, a boiler water with a sodium hydroxide content low with respect to the total solids present but high in concentration might not cause a deposit. This is because salts other than sodium hydroxide apparently aid in the prevention of the deposits.

The salts which form a dry powder in the superheated steam apparently adhere to the surface of the droplet of concentrated pasty sodium hydroxide, and if present in sufficient amount entirely coat the particle and allow it to pass through the turbine without sticking to the blades. Such a method of prevention naturally requires large amounts of the dry powder in proportion to the sticky material. The plant tests and laboratory experiments indicate that if sodium sulphate is to be used to prevent turbine fouling it must be present in amounts greater than four or five times the actual sodium hydroxide present. Power-plant operators hesitate to increase the total solids in the boiler water because they fear carry-over. However, if this is properly controlled and the carry-over does not become excessive, the deposits will be prevented.

The application of the inorganic-salt treatment to one large central power plant while still in the experimental stage showed that the periods of turbine washings were reduced from four weeks to about twelve weeks, or from twelve times a year to four. It is quite possible that when the water treatment is better understood washing in this plant may be entirely eliminated. The cost of the treatment used has been low, less than $500 per year, and the savings have been materially high since corrosion has also been reduced.

The application of these data to power-plant operation should be made only after a careful study of the conditions existing at the particular plant and changes which are made should be under the control of a chemical engineer who thoroughly understands this field of water treatment.

Conclusions

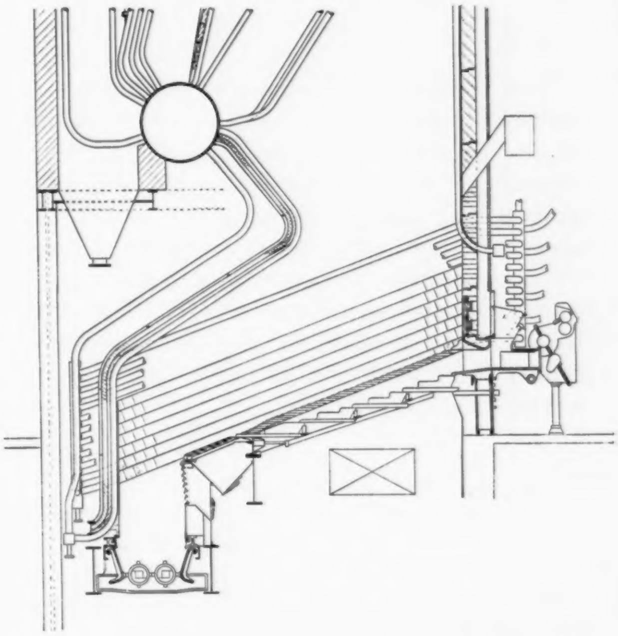
A summary of conclusions drawn from the results of this work is as follows:

(1) The basic material causing turbine-blade fouling is sodium hydroxide.

(2) Inorganic salts, such as sulphate, chloride and carbonates, if present in sufficient amounts, will prevent turbine-blade fouling.

Rear Arch for Multiple-Retort Stoker

The illustration shows a rear arch construction that has been proposed for use with multiple-retort stokers when burning coals that have practically no coking or caking characteristics. With the usual furnace arrangement such a coal would tend to drift on the stoker grate, toward the extension grate, dump grate or clinker pit. In the construction shown, which has been found effective with traveling or chain grate stokers burning fine coal, the gases from the rear are brought forward to mix with the richer gases from the front of the stoker. With long flaming coals over-fire air under a comparatively high pressure could be employed to advantage, the nozzles being located 5 ft or more above the stoker grate, depending upon the boiler setting.



Suggested arrangement of rear arch for multiple-retort stokers burning non-caking coals

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The largest 3600-rpm turbine-generator to date is a 40,000-kw G.E. unit recently ordered by the Appalachian Electric Power Company for an extension to its power plant at Logan, W. Va. This is a high back-pressure machine which will take steam at 1260 lb pressure, 925 F temperature and will exhaust to the present station system. The generator of the new unit will be hydrogen cooled. It is expected to be in operation early in 1937.

The Metropolitan Section of the A.S.M.E. has established a Power Round Table Discussion Group which will meet monthly, or oftener if found desirable, to discuss informally problems of mutual concern to power engineers in the Metropolitan District. These conferences while open to both central-station and industrial power men are expected to be especially helpful to the latter who heretofore have had no regular forum for the exchange of opinions and information.

A Control Chart for Interpretation of Coal Sampling Data

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The tendency to regard the characteristics of a coal sample as an exact measure of the quality of the lot, instead of considering it as an observed value of a variable which fluctuates between determinable limits, often leads to erroneous conclusions. The author shows how to prepare and use a control chart that will indicate from day to day whether the quality of a given coal is being maintained within required limits.

IN an effort to get the maximum return for his fuel dollar the consumer wants to measure the quality characteristics of coal in order to:

1. Select a suitable and economical product for his use.
2. Be sure that its quality is controlled and maintained within required limits; in other words, that he gets what he pays for.
3. Improve his methods and increase the efficiency of his use of the coal.

Variability of the quality characteristics of a given coal as it is tested from lot to lot is one of the chief difficulties in arriving at correct decisions as to suitability, cost, quality control, equipment, methods, etc., with respect to the coals being considered or used. Often when a decision is based upon the results of a test, or a few samples, the next results available will show such different quality that it seems to require a reversal of the original decision.

Obviously, such a situation is not conducive to economy for the consumer, and is the chief source of misunderstanding and trouble between consumer and producer.

Apparently, much of this difficulty is due to the tendency to accept a sample result as an *exact measure* of the quality of the lot from which it was taken, instead of considering it as an *observed value* of a variable[1] which fluctuates within limits that are easily determined for a given coal. With the first conception every result is a surprise; with the second, every result teaches us something about what to expect in the future, how to measure and predict the variability of the quality, and how to control it.

Control charts based upon statistical data are being used by the Bell Telephone System and other large industrial concerns to measure the variability and check the quality control of materials; to compare the efficiency of different processes and methods of manufacture, for predicting, controlling and checking the quality of manufactured products, and in solving and interpreting many related problems which involve variables.

The purpose of this article is to show how the coal consumer or the producer may utilize similar control charts, designed particularly for coal, as a means of showing from day to day whether the quality of a given prepared coal is being controlled and maintained within the required limits.

Control Charts

The Control Chart gives an *expected average quality*, and *limits* for variability of individual and group results. It enables one to decide more intelligently the following question which frequently arises: "When the current results are materially above or below the average quality, and are interpreted in relation to all available data, do they indicate that a significant change has, or has not, occurred in the average or the variability of the quality of this coal?"

The use of the proposed Control Chart (Fig. 1*a*) for prepared coals is comparatively simple. The chief control features of the chart consist of three lines which are drawn to scale, the center line representing the *expected average* ash, sulphur or other characteristic for the given prepared coal, while the other two lines enclose a band above and below, within which approximately 99 per cent of all the sample results from that coal are expected to fall. (See Fig. 1*b*.)

The individual results as received from the laboratory are numbered in the order of occurrence and plotted to scale on the chart. As long as the results plotted meet the requirements "approximately 99 per cent within the control lines" and as long as the sampling has not been

[1] The variability shown by the sampling results is really an apparent variability. It is the combined result of:

(*a*) The *true variability*, which is the variability of the actual quality of the coal from lot to lot. It is always less than the apparent variability.

(*b*) The *sampling errors*, or the errors occurring in the measurement of quality (*b* is sometimes more important than *a*).

This paper deals with the "apparent variability," as that must be measured before it is possible to determine the measure of the true variability.

In 1909 E. G. Bailey showed that the variability of the results of the samples from a single lot of coal (sampling errors) might be measured and predicted by the Laws of Probability. In 1930 Grumell and Dunningham (British Engineering Standards Association, No 403-1930) showed that the results of similar samples from different lots of a given coal (apparent variability) might be measured and predicted in the same manner. This seems to indicate that the "true variability" of a given coal is also a variable which may be measured and predicted by statistical methods. Morrow and Proctor say, "The actual distribution usually checks closely with the probable distribution with slight exceptions that will be noted later." (Variables in Coal Sampling, A.I.M.E., T. P. 645, page 6.)

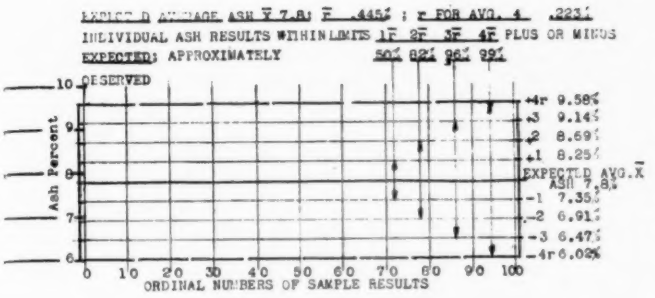

Fig. 1a—Ash control chart

changed, both producer and consumer can be confident that the required control and preparation of the coal is being maintained within reasonable limits.

Preparing the Chart

Fig. 1*a* shows a Control Chart for individual ash results from a given coal for which the *expected average*, $\bar{X}$, is 7.8 per cent ash, and the *expected probable error*, $\bar{r}$ is 0.445 per cent. These two values determined from sufficient data on the given coal, as specified later in an example, give a basis for constructing the chart and for comparing the distribution of new groups of observed results with the expected distribution. Proceeding with the chart, a suitable vertical scale is marked off for ash, and a horizontal scale for the sample results numbered in the order of occurrence. A line is drawn at 7.80 per cent ash representing the expected average as $\bar{X}$. The upper control line is drawn at 9.58 per cent ash, which is 1.78 per cent, or 4 times 0.445 per cent (the value of $\bar{r}$) above the average 7.8 per cent. The lower control line is drawn at 6.02 per cent which is 4 times the value of $\bar{r}$ below the average 7.8 per cent. The intermediate limits $1\bar{r}$, $2\bar{r}$ and $3\bar{r}$ above and below the average may be indicated on a scale as shown, or may be drawn in. These are used to check the distribution of averages of sub-groups of four or sixteen individual results, and to compare the observed with the expected distribution of individual results at any time after twenty, thirty or more results have been plotted.

Averages of Groups of Four or More Results

The averages of groups of four results, according to the laws of probability, will distribute themselves about the average $\bar{X}$ in a manner similar to the individual results, but within narrower limits. The value of $\bar{r}$ for averages of groups of individual results decreases inversely as the square root of the number of results which are averaged in the groups. Therefore $\bar{r}$ for groups of four in the example given is 0.445 divided by 2 (the square root of 4) which gives 0.223 per cent. In other words, $\bar{r}$ for averages of groups of four should be just half the value of $\bar{r}$ for the individual results, and 99 per cent of these averages are expected to fall within the limits $2\bar{r}$ on the chart, this being half the interval within which 99 per cent of the individual results, are expected to fall. Likewise averages of groups of sixteen should fall 99 per cent within the $1\bar{r}$ limits of the chart.

Evidence of Control

Dr. W. A. Shewhart, in "Economic Control of Quality of Manufactured Product," p. 144, says: "To be able to say that a product is *controlled*, we must be able to predict, at least within limits, the future variations in the quality."

It will be shown that one can predict with surprising accuracy the variability of the sampling results for a given coal, indicating that its quality is controlled. As long as the current sampling results fit the chart it is strong evidence that no material change has occurred in the quality or the sampling, and that the chart has been correctly prepared for that coal. One must keep clearly in mind that it is not possible to predict whether a given result will be plus or minus, nor where it will fall on the chart, but one can predict with reasonable certainty that certain percentages of all results will fall within any given limits.

We should look for trouble (a material change in sampling, preparation, mining or inherent quality) when more than one individual result in a hundred falls outside the control lines, and when more than one average of groups of four falls outside the $2\bar{r}$ line, or if the observed distribution for a considerable number of results does not approximate the expected distribution. It is not to be expected that small groups of results will make a smooth frequency curve[2] nor that the plus and minus distribution will always be equal.

Ninety-nine per cent of the averages of groups of sixteen individual results will be expected to fall within $1\bar{r}$ limits shown on the chart. Similarly, monthly averages of twenty-five results will be expected to fall within limits 0.8 $\bar{r}$, or to show a variability one-fifth as large as that of the individual results. From this and from Table II, it will be seen that relatively large variations in weekly or monthly averages are expected *chance variations* and *not evidence* of lack of control. The main point is that there is no need to worry about quality of individual lots or small groups of lots as long as they fit properly on the control chart.

Test for Control

Having prepared the Control Chart for the given coal, we are ready to test out this coal for control. The individual sample results[3] are plotted as they are received (Fig. 1*b*), and the first four are averaged, noting that the individual results are well within the control lines, and the average slightly below the expected general average. The next two groups of four show similar results. The

[2] See *A. S. T. M. Manual on Presentation of Data*, 1933.
[3] These are actual results in the order of occurrence.

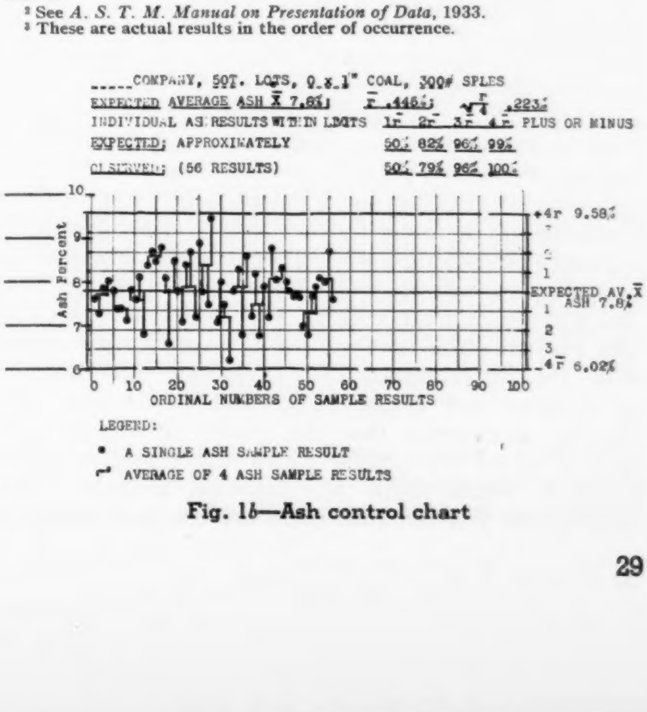

Fig. 1b—Ash control chart

fourth group falls close together, with an average 0.8 per cent above the expected general average. Now instead of getting excited because of these four high ash results it should be realized that this is to be expected, although it might indicate trouble. Watching to see what comes next, we are reassured by the next two groups falling on or close to the expected average quality. The seventh and eighth groups are scattered almost from one control line to the other, but their averages 0.6 above and 0.6 below are well within control lines for groups of four, which are the $2r$ lines of the chart, within which 82 per cent of the individual results should fall. Six additional groups of four show distribution well within the control chart.

We now check up to see how the distribution of the fifty-six results which have been plotted agrees with the distribution expected between the limits $1\bar{r}$, $2\bar{r}$, $3\bar{r}$ and $4\bar{r}$, and find it as follows:

Within the limits, average $\bar{X}$ plus or minus	$1\bar{r}$	$2\bar{r}$	$3\bar{r}$	$4\bar{r}$
Expected (from probability integral)	50%	82%	96%	99%
Observed	50%	79%	96%	100%

Fig. 2 shows a similar control chart for 150-lb samples from single railroad cars of a coal for which the expected average $\bar{X}$ is 5.96 per cent ash and $\bar{r}$ is 0.368 per cent. The control lines $4\bar{r}$ are at 6.44 per cent and 4.48 per cent and 157 consecutive individual ash results are shown in the order of occurrence with 39 groups of 4. Individual result No. 1 falls just above the upper control line and No. 86 just below it, while No. 140 falls just above the lower control line (99.99 per cent of all results are expected to fall within limits $5.7\bar{r}$). All of the group averages fall within $2\bar{r}$ limits on this chart, as they did on Chart 1*b*. The distribution of individual results compares as follows:

Within the limits, average $\bar{X}$ plus or minus	$1\bar{r}$	$2\bar{r}$	$3\bar{r}$	$4\bar{r}$
Expected (from probability integral)	50%	82%	96%	99%
Observed	50%	76%	96%	99%

The evidences of control as shown by Charts 1*b* and 2 are supported for both of the coals by other data which are not shown for lack of space.

Further Evidence

Table I shows data on similar groups of samples of twenty-seven different prepared coals. It will be noted that in every case there is good agreement between the observed and the expected distribution, showing that the expected distribution as predicted from the value of r, determined from the actual deviations of sample results from each coal, was close enough to the observed distribution for practical purposes in every case.

Among more than one hundred other sets of data examined in this manner all but two or three showed an agreement of observed with expected distribution which was close enough for practical purposes. These data included ash, sulphur, volatile, Btu, fusion, and float and sink results. The results of these investigations agree with the experimental data presented by Bailey,[4] by Grumell and Dunningham[5] and by Morrow and Proctor[6] as evidence that the quality of a given coal from lot to lot is a variable which can be measured and predicted within limits by statistical methods. The belief seems justified that there are few well prepared coals which will not meet Dr. Shewhart's requirements for evidence of control as previously mentioned.

TABLE I

COMPARISON OF *OBSERVED DISTRIBUTION* OF ASH RESULTS OF SAMPLES FROM COMMERCIAL LOTS OF DIFFERENT PREPARED COALS WITH *CALCULATED*, OR *EXPECTED DISTRIBUTION*

Taking Observed Values of $\bar{x}$ & $\bar{r}$ as Expected Value

No.	Size of Coal	[7]No. Sples.	Wt. of Sple.	% Ash $\bar{X}$	Prob. Error $\bar{r}$	Percentage of Results Actually Found within Plus and Minus Limits of Av. Ash $1\bar{r}$	$2\bar{r}$	$3\bar{r}$	$4\bar{r}$	$5\bar{r}$
	Large Groups									
1	Plus $1^1/_4''$	115	250	4.7	.226	50%	82%	97%	99%	100%
2	$0 \times {}^1/_2$	112	120	5.2	.437	64	81	94	99	100
3	2×4	100	27	5.8	.77	50	86	96	99	100
4	$0 \times {}^5/_8$	157	150	6.0	.37	50	82	96	99	100
5	0×2	100	350	6.0	.13	50	82	94	98	100
6	$1^1/_8 \times 2$	100	120	6.1	.45	51	83	95	97	100
7	$0 \times 1^1/_8$	100	280	6.1	.14	53	85	91	96	98
8	$0 \times {}^3/_4$	100	180	6.2	.325	50	86	97	98	100
9	$0 \times {}^3/_8$	110	108	6.4	.133	51	80	95	100	...
10	48M × 4	154	16000	6.85	.124	55	81	92	98	99
11	ROM	293	195	7.0	.51	50	82	95	98	99
12	0×4	100	900	7.09	.119	53	81	94	98	100
13	0×2	200	250	7.7	.965	48	84	96	99	100
14	ROM	310	800	7.8	.23	50	82	95	98	99
15	ROM	120	1800	7.9	.24	50	82.5	96	100	...
16	0×4	100	900	8.41	.173	50	84	96	99	100
17	48M × 4	154	16000	9.44	.31	51	82	95	100	...
	Small Groups									
18	$0 \times {}^1/_2$	39	200	6.8	.34	51	84	93	97	100
19	0×4	37	140	6.5	.28	46	78	91	94	100
20	0×2	32	300	8.4	.40	47	84	97	100	...
21	$4M \times {}^1/_2$	35	70	7.6	.40	46	86	97	100	...
22	ROM	38	300	8.8	.70	47	84	97	100	...
23	0×2	63	200	6.0	.37	50	81	96	100	...
24	ROM	51	1200	7.0	.33	50	86	96	98	98
25	0×1	28	300	7.7	.418	50	75	96	100	...
26	0×2	24	200	7.8	.79	54	87	96	96	100
27	0×2	24	200	7.5	.74	54	87	96	96	100
Percentage Expected within Limits Shown When Preparation and Sampling Are the Same throughout the Group						50	82	96	99	100

Statistical Values Needed

For the proposed control chart we need the *Expected Average Quality* and the *Expected Probable Error*, indicated herein by $\bar{X}$ and $\bar{r}$, respectively.[7]

The expected values of $\bar{X}$ and $\bar{r}$ should be taken as equal to the observed values of X and r as determined from sufficient data, all of which were secured when production, preparation and sampling conditions were essentially the same as should obtain for the future.

Quantity of Data Needed

The greater the variability shown by the sampling results the more data is needed for a reliable estimate of $\bar{X}$, the *expected average quality*, and of $\bar{r}$, the *expected probable error*, from which we find the *control interval*, $t = 4\bar{r}$.

It has been shown that the variability of averages of groups of four individual sample results is expected to be just half that of the individual results; that the *control interval t* for averages of groups of four, sixteen or twenty-five results will be $^1/_2$, $^1/_4$ or $^1/_5$, respectively, of that for individual results. These intervals measured in terms of r are $2r$, $1r$ or $0.8r$. This means that there are 99 in 100 chances that the average of such a group will fall within the corresponding limits of the true average, and 1 in 100 chances that it will not. It is also true that there are 50 in 100 chances that the average of such a group will fall within limits only $^1/_4$ as great as those given above.

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[4] E. G. Bailey, "Accuracy in Coal Sampling."
[5] E. S. Grumell and A. C. Dunningham, British Engineering Standards Assn., 1930, No. 403.
[6] J. B. Morrow and C. P. Proctor, "Variables in Coal Sampling," A.I.M.E. *Technical Publication 645*
[7] For other statistics and their uses see *A.S.T.M. Manual on Presentation of Data*, or other statistical text.

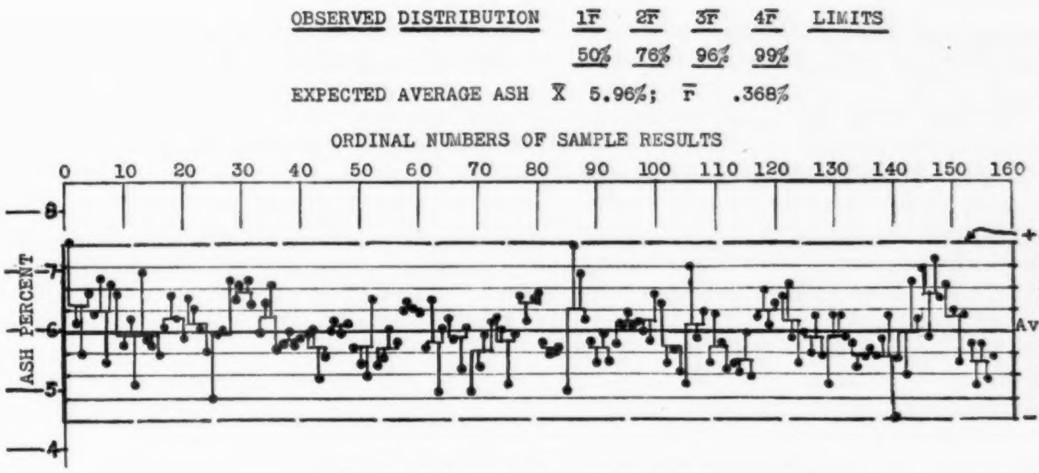


Fig. 2—Ash control chart for 150-lb samples

The use of Table II to determine the required number of sample results will be illustrated as follows:

Example

Given sixteen results, $X = 6.5$ per cent, $r = 0.40$ per cent, $t = 4r = 1.60$ per cent. Find the number of results which will be sufficient to give reliable values for $\overline{X}$, $\bar{r}$ and t:

With 0.40 per cent as an estimate of r inspect Table II. It will be seen that there are 99 in 100 chances that the average of sixteen results will be within $1r$, or 0.40 per cent of the *true average.* It will be noted that an average of 64 results should fall within $0.5r$ or in this case 0.20 per cent of the true average. Considering accuracy needed, time, cost of sampling, etc., and the fact that there are 50 in 100 chances that the result will be within 0.20/4 or 0.05 per cent, we may decide to take 48 more samples, making 64 available. Suppose the 64 results show $X = 6.4$ per cent and $r = 0.44$ per cent from which $t = 1.76$ per cent.

Now we may say there are:

99 in 100 chances that X is within $0.5r$ or 0.22 per cent, and

50 in 100 chances that X is within 0.055 per cent of the *true average* of all results from that coal, as long as present control is maintained.

The table shows similar limits for t to be $1.41r = 1.41 \times 0.44 = 0.62$ per cent from which there are:

99 in 100 chances that t is within 0.62 per cent, and

50 in 100 chances that t is within 0.16 per cent of the *true control interval.*

If no other good data are available the observed values of X, r and t may now be taken as the expected values with which to construct the Control Chart as follows: $\overline{X} = 6.4$ per cent; $\bar{r} = 0.44$ per cent; $t = 1.76$ per cent.

It is important in sampling the given coal that the same definite routine be followed not only in taking each gross sample, but at each step in the field and laboratory reduction of the samples. Each gross sample should be taken by an equal number of increments uniformly distributed throughout the lot sampled. Each increment should be representative of the entire flow when it is taken. This is best done by cutting the entire stream with a suitable receptacle which is not allowed to overflow as it is passed at uniform speed into one side of the stream and out the other.

At each stage in the reduction the size and the quantity taken should be approximately the same for all samples of the given coal. The same laboratory routine should be followed for analysis.

TABLE II

NUMBER OF SAMPLE RESULTS REQUIRED FOR EXPECTED VALUES OF X AND t

	To Give 99 Chances in 100 that	
Number Sample Results Required	Avg. X Will Be Correct within Limits	Control Interval t for Individual Results Will Be Correct within Limits
16	1.00r	2.83r
25	0.80r	2.26r
36	0.667r	1.88r
64	0.500r	1.41r
100	0.400r	1.13r
225	0.267r	0.75r
400	0.200r	0.56r
625	0.160r	0.45r
1600	0.100r	0.28r

r = Probable Error for Individual Observed Results.
$t = 4r$ = Control Interval for Individual Observed Results, the interval between $\overline{X}$ and the Control lines on the Control Chart.

All of the data used to determine expected values should be from samples taken when control of production, preparation and sampling are the same as should obtain for the future. Any change in the sampling (taking reduction and analysis of samples) *may* seriously change the value of r, but would not change the value of $\overline{X}$, unless a constant error existed before or occurred after the change in the sampling.

In cases where sufficient good data are not already available it will be best not to wait to accumulate enough data for very close estimates of $\overline{X}$, $\bar{r}$ and t before beginning to use the Control Chart, but to start with the observed values given by, say, one-fourth of the number decided upon as necessary. Then $\overline{X}$, $\bar{r}$ and t can be corrected if necessary when each additional one-fourth has been added to the chart.

Obviously, one will continue to make such corrections as the increasing knowledge of the variability of the given coal indicates will give more accurate predictions.

In some cases the apparent variability of the coal has been materially reduced by increasing the accuracy of the sampling. Important errors frequently occur in reducing the gross sample for analysis.

Choice of Statistics

The reasons for using the *probable error*, r, instead of the *standard deviation*, σ, which is generally used in modern statistical science and for control charts are as follows:

(a) r has been used by Bailey, Grumell and most other investigators of coal.

(b) $4r$, expected to include 99.3 per cent of the results, gives a *control interval* only 0.9 as wide as 3σ, expected to include 99.73 per cent of the results.

(c) The use of r gives a series of easily remembered numbers, 50 per cent, 82 per cent, 96 per cent and 99 per cent expected within the limits $1r$, $2r$, $3r$ and $4r$, respectively, with which the probable distribution of any group of results can be visualized when no charts or even a grouping of the data is available.

(d) The $2r$ and $1r$ limits for individual results give control limits for averages of sub-groups of four and sixteen results, respectively, making it convenient to compare all three on a single chart.

(e) If r is taken as 0.6745σ it should have the same efficiency as σ.

EXAMPLE OF CALCULATION OF STATISTICAL VALUES

Ash results 28 Lots 50 T RR cars; 1 Sample, 300 lb each Car; Co........
Coal 0 × 1 in. Spld........, 1935 Calc. by.......... Date............

Lot No.	Observed % Ash Each Lot	x Deviation from Av. % Ash	x^2 Deviations Squared	Lot No.	Observed % Ash	x Deviation from Av. % Ash	x^2 Deviations Squared
1	7.1	.6	.36	15	8.1	.4	.16
2	8.0	.3	.09	16	8.3	.6	.36
3	7.5	.2	.04	17	8.0	.3	.09
4	6.2	1.5	2.25	18	7.8	.1	.01
5	7.8	.1	.01	19	7.7	0	0
6	8.3	.6	.36	20	7.7	0	0
7	6.8	.9	.81	21	7.0	.7	.49
8	8.6	.9	.81	22	6.8	.9	.81
9	7.2	.5	.25	23	7.7	0	0
10	8.2	.5	.25	24	7.9	.2	.04
11	6.8	.9	.81	25	8.1	.4	.16
12	7.9	.2	.04	26	8.0	.3	.09
13	7.2	.5	.25	27	8.7	1.0	1.0
14	8.8	1.1	1.21	28	7.6	.1	.01
		Σ or total		28	215.9	13.8	10.76
		Symbols		n	Σ Ash %	Σ x	Σ x^2

X, Av. or Mean % Ash $= \frac{215.9}{28} = 7.71$ %

σ, Standard Deviation $= \sqrt{\frac{\Sigma x^2}{n}} = \sqrt{\frac{10.76}{28}} = .620$

r, Probable Error $= 0.6745\sigma = 0.6745$ times $0.620 = .418\%$

e, Av. Deviation or Av. Error $= \Sigma \frac{x}{n} = \frac{13.8}{28} = .493\%$

r_p, Probable Error by Peter Formula $= .85e = .85$ times Av. Dev. $.493 = .419$

t, Control Interval $= 4r$, or 2.70σ, $4 \times .418$, or $2.70 \times .620 = 1.674$

The probable error, r, by the Peter Formula, $0.85\,\Sigma \frac{x}{n}$ usually checks closely with $0.6745\sqrt{\frac{\Sigma x^2}{n}}$ when small and n is 30 or more. When n is large the calculations may be shortened by grouping the data into cells in the usual manner.[2] Constant errors, which tend to give all results too high, or too low, must be avoided in the sampling.

Conclusions

1. The *quality* of commercial lots of a given prepared coal, with respect to any characteristic is a *variable* and, therefore, can never be determined *exactly*, but it can be *measured* and *predicted* for purposes of comparison or control within statistical limits. Only when these limits are known is real confidence justified in using the sampling results.

2. The evidence that the variability shown by a given prepared coal may be predicted is evidence:

(a) That the actual lot to lot variability of the coal is due to a constant system of chance causes, and is therefore *controlled*.

(b) That the same may be said of the sampling in the given case.

3. In this article an effort has been made to keep mathematical and theoretical discussion to a minimum, but to give something definite which the average producer or consumer may try out, and use as he builds up more and more complete data on the given coal. More complicated methods and tests for control,[8] which are necessary when r is large and the number of sampling results relatively small, are not given in this article, as it is believed that, in interpretations of coal sampling data where r is small, the number of results relatively large, and each includes a large number of pieces, the simple methods outlined will give good results.

4. The ordinary coal chart shows the quality of past lots; if we add the control features, it predicts future quality and variability. As long as current results fit the chart, it is probable that control of quality and sampling is being maintained. It shows promptly when we should look for trouble.

5. The Control Chart for a given coal forms a background of past and expected ups and downs against which we may interpret the significance of current results.

[8] See Supplement A & B *A. S. T. M. Manual on Presentation of Data.*

World Power Conference Committees Announced

As announced in these columns last month the Third World Power Conference is to be held in Washington, D. C., September 7 to 12, 1936. The officers and the executive committee have now been selected and a preliminary meeting of the committee has outlined the agenda which will deal with (1) technical, social and economic trends; (2) organization of the fuel industries; (3) regulation of public utilities; (4) national and regional planning; and (5) distribution.

President Roosevelt will be the Honorary President of the Conference and Secretary Ickes will be Honorary Vice-President and Chairman of the American Committee. Dr. W. F. Durand will be Chairman of the Conference and Vice-Chairman of the American Committee. O. C. Merrill, who it will be recalled was Secretary of the American Committee in the former conferences, will be identified with the present conference in the capacity of Director and J. D. Wolfsohn will be Executive Secretary.

The Executive Committee will be made up of the following:

Chairman, Morris L. Cooke; C. W. Appleton, General Electric Company; Floyd L. Carlisle, Niagara Hudson Power Co.; Frank D. Comerford, president Edison Electric Illuminating Co., Boston; Gano Dunn, president J. G. White Engineering Corp.; R. H. Fernald, University of Pennsylvania; A. C. Fieldner, Bureau of Mines; Daniel C. Green, Middle West Utilities Co.; David E. Lilienthal, Tennessee Valley Authority; William McClellan, president Potomac Electric Power Co.; Frank R. McNinch, chairman Federal Power Commission; Gen. Edward M. Markham, chief of engineers; O. C. Merrill, consulting engineer; I. E. Moultrop, T. W. Norcross, chief engineer Forest Service; Richard Southgate, State Department; C. E. Stephens, vice-president Westinghouse Electric & Manufacturing Company; J. C. Bonbright and J. D. Wolfsohn, executive secretary National Power Policy Committee.

Liability for Patent Infringement

A review of numerous court decisions showing that it is unlawful to make, sell or use a patented device without permission; or to repair a patented article to the extent of rebuilding or renovating it. Joint infringement liability is explained as is also recent decisions governing control over resale of a patented device.

By LEO T. PARKER

Attorney at Law, Cincinnati, Ohio

IT IS interesting to observe that far back in the early history of England the word "patent" was created by the King who gave to his influential friends and supporters the exclusive rights to import or to sell certain necessities of life such as salt, sugar, flour and the like. By this plan, the holders of these valuable patent grants were induced perpetually to support the Crown by being enabled to extort exorbitant prices for their products from the general public, and thus earn a luxuriant livelihood with little effort.

Later patent laws were enacted which offered to the inventors of new and useful things the exclusive grants for limited periods of time to make, sell and use the products of their brains and originality.

When the U. S. Patent Laws were first formulated, our forefathers realized the necessity of drafting them especially for the purpose of creating interest on the part of individuals who were naturally endowed with inventive genius, so that these individuals might be induced to exert this special faculty toward inventing new and improved things by which the public would benefit. In other words, the patent laws were *not* formulated for the purpose of enabling inventors to hold a monopoly by which to obtain exorbitant prices for patented commodities, but for the purpose of inducing them to invent new things from which the public might benefit.

Obviously, therefore, in order to create and maintain interest on the part of inventors it became necessary that the courts uphold the fundamental principles of the laws intended to protect patentees from unauthorized use of their inventions. And in order to compensate inventors for their contribution to advancement of civilization, the public was and still is required to pay the price demanded by the owners of a patent for use of his brains, so to speak, during the term of the patent. After the expiration of the patent, the device may be freely and unrestrictedly manufactured and utilized by the public without further payment of royalties.

Unlawful to Make, Sell or Use

A patent is the most perfect form of monopoly from which profiteering, so to speak, is legalized. This monopoly has been recognized by the courts since the early case of Wilson v. Rausseau, 4 Howard 646. In this early case the Court decided that a patentee has the exclusive right to *make, sell and use* his invention for the term of years specified in the patent grant. Also, in Cantelo, 12 Pat. Law R. 262, the exceptionally well written opinion of the Court explains the rights of a patentee in the following language:

"The patentee has the sole right of making, using and selling the articles, and he may prevent anybody from dealing with them at all. Inasmuch as he has the right to prevent people from using them, or dealing in them at all, he has the right to do the lesser thing, that is to say, to impose his own conditions. *It does not matter how unreasonable or how absurd the conditions are.*"

Thus, contrary to widespread opinion among engineers, any person who makes a patented device for his own use, without authority of the inventor, is liable for infringement, although the maker does not sell the invention or publicly use it.

On the other hand, it is important to know that a patentee may not legally control the *resale* price or restrict the uses of a patented device *after selling it.* However, it is permissible for an inventor to restrict the uses of a patented invention under a valid license contract, and a clause in a license contract is valid by which the purchaser agrees to use the invention only for specified purposes. In other words, a licensed user of patented equipment is bound to abide by the reasonable terms of a license contract, by which the patentee agrees for a stipulated sum to permit the licensee to use a particular invention for specified purposes in a limited territory.

Under these circumstances the patentee receives remuneration in accordance with the rights granted the licensee, and the latter is bound to abide by the agreement. But, as previously mentioned, recent higher court decisions hold that *all agreements are illegal* by which patents are utilized in an attempt to legalize price fixing for the resale of patented products. Therefore, the outright purchaser of a patented machine, device or other thing, is *not* limited in any sense to the uses he makes of it.

Another important point of the law is that a license contract may be invalid for many reasons. For example in a recent case (226 U. S. 20) the Supreme Court of the United States held that an agreement is illegal by which the *output* of a patented product is controlled or limited by the inventor.

Also, a license agreement is invalid by which a patentee seeks to eliminate competition. In a recent case (258 U. S. 451) a license contract contained a stipulation obliging the licensee user of the machine not to use machines made and sold by competitive manufacturers. The Court held this contract invalid.

It is also important to know that disguised lease contracts which legally are contracts of sale, do not enable patentees to restrict the uses of the invention.

It has been held that a contract is void by which a purchaser agrees to pay the seller certain amounts in installment payments, with the privilege of purchasing the device for an insignificant amount such as $1 after the installments are paid. A contract of this nature is legally a sale contract and *not* a lease contract.

Right to Repair

Many plant owners and engineers have become involved in litigation as a result of repairing or overhauling patented equipment on the unfounded belief that a purchaser of patented equipment is privileged to make any and all necessary repairs of the same. Therefore, it is important to know that a plant owner is liable as an infringer where the engineer authorizes *extensive* repairs of a patented machine, device or equipment.

For illustration, in the leading United States Court case of Howardson v. St. Louis Co., 77 F: 740, the Court clearly explained the law on this subject and explained that the rule is well established that any one who purchases a machine or mechanical contrivance has the right, by virtue of his purchase from the patentee, to repair a part of the machine or device which happens to be broken through accident, but when a patented machine is accidentally destroyed, or when it is practically worn out, the owner under the guise of repairing it, cannot practically remake the machine. In other words, while the owner of a patented device may make ordinary repairs he is liable for infringement if he performs such extensive repairs as may be considered by a court as taking a worn out device and making it serviceable.

Infringement Liability

A plant owner, who infringes a patent, is liable for the profits lost by the inventor, plus *all* damages sustained by the inventor. Also, if the infringement is willful the infringer may be held liable for *three times* the normal profits and damages. And the fact that infringement is *not* intentional, does *not* relieve the infringer from liability for normal profits and damages.

Recently a higher court held that all acts of the infringement of a patent must be accomplished in the United States. However, if a single part, or the complete patented invention, is shipped from a foreign country and used here, the user is liable as an infringer, although the foreign maker may not be liable. This is true because an unauthorized user of a patented device is equally as liable as the maker or seller who is located in the United States.

Still another interesting phase of the law is that where several persons conspire to avoid paying royalties to a patentee for the use of his invention, and each person performs a distinctly separate act from the others, all of the persons are liable if the concerted acts actually result in infringement.

An example of this is found in a recent case (80 F. 712) in which the testimony disclosed that a dealer advertised to supply a single part of an invention which when combined with other well-known parts, obtainable from common sources, produced an infringing product. The Court held the advertiser and also the persons who purchased the part and made the infringing product liable as co-infringers.

It is also important to know that the owner of a patent is privileged to sue either the plant owner, seller or user of the invention or all of them; or he may include the engineer who instigated the unauthorized use. Therefore, while the patentee may forestall extensive infringement with little difficulty, usually he sues the manufacturer, or plant owner and, after infringement is established, he may obtain an injunction to prevent the continuation of the infringement by all other parties.

Kinds of Patents

Few engineers have obtained clear and definite knowledge of the kinds or classifications of patents. At present patents are subdivided into classes usually known as Mechanical, Process, Composition, Article of Manufacture and Design. The four first mentioned classes of patents issue for 17 yrs. A design patent is granted for $3^1/_2$, 7 or 14 yrs, as the inventor specifies by making increased Government fees where the longer terms are desired.

Mechanical patents issue on purely mechanical devices. Process patents protect methods of making an old or new article, whether the process be mechanical, manual or chemical. Composition patents are issued on things made from compositions of matter or mixtures of chemicals. Articles of Manufacture patents relate to articles which are to be manufactured but do not include any of the former classes. Design patents relate exclusively to the external appearance of an article which must be *ornamental and attractive*. No mechanical function may be protected by a Design patent, and if the design of the article is to increase its efficiency such a patent will not be allowed.

The infringement laws are the same for all classes, although considerable variations are apparent in the procedure of obtaining the different kinds of patents.

How to Avoid Infringement

A plant owner may avoid losses by infringement of patents by contracting with contractors to make the installations. Under these circumstances the contractors assume all liability.

For example, in Jackson v. Nagle, 47 F. 703, it was disclosed that a principal contractor was awarded a contract. He made a contract with a subcontractor. A patentee sued both the principal contractor and the subcontractor for infringement of a patent as a result of the subcontractor using certain structures which infringed the patent. The Court held both the principal contractor and the subcontractor liable for infringement and explained the law, as follows:

"A contractor who makes an agreement to perform certain work necessarily assumes the risk of infringing upon the exclusive patent rights of others, and if he does so infringe, he cannot avoid responsibility because he was doing the work for other persons. If a contractor violates the patent rights of another, he is, of course, answerable for the infringement. *A subcontractor stands upon the same footing.*"

STEAM ENGINEERING ABROAD

As reported in the foreign technical press

High Steam Pressures and Temperatures in German Merchant Marine

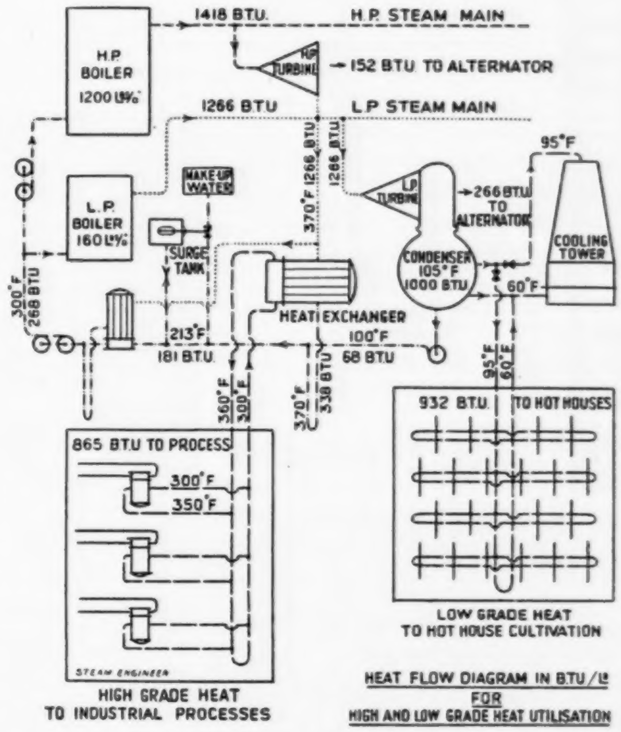
Higher steam pressures appear to be employed in the German Merchant Marine than in that of any other country. According to *Zeitschrift des Vereines deutscher Ingeneuire,* two new vessels, the "Scharnhorst" and the "Gneisenau," constructed for service to the Orient, employ steam pressure of 711-lb gage and steam temperature of 878 F. Another vessel, the "Potsdam," which employs turbine-electric drive and is the first vessel to be completely equipped with Benson boilers, operates with a steam pressure of 1280 lb abs and a temperature of 896 F. Its four boilers supply two 10,000-kw turbine-generators, and the fuel consumption on its maiden voyage, recently completed, was 0.559 lb of oil per bhp-hr.

Grid Reduces Reserve Capacity

In a recent address before the Institution of Electrical Engineers (Great Britain), J. M. Kennedy referred to the reduction in reserve generating capacity that has so far been effected by the Grid. In 1929 the spare plant capacity of the stations and systems now connected into the Grid was 83 per cent. This has been gradually reduced until it is now 62 per cent. This reduction of 21 per cent represents the freeing of approximately a million kilowatts capacity which otherwise would have to be kept in reserve. This saving to date respresents about one-third the cost of the Grid and with a further progressive reduction in spare capacity it is estimated that the saving will ultimately equal or exceed the cost of the Grid. The address is printed in full in *The Engineer* of November 1, 1935.

Combined Electricity and Heating Service for British Industrial Community

The first central station to be constructed in England for the supply of both electricity and heat, in the form of hot water, to local industries will soon be undertaken by the Worksop Development Company in cooperation with the Local Council of Worksop. The plan, as outlined in the November issue of *The Steam Engineer,* provides for a high-pressure (1200 lb) steam plant at the Manton Colliery, just outside Worksop. Steam at this pressure will be supplied to a high-pressure turbine-generator exhausting at 150 lb to either a low-pressure turbine or to a heat exchanger from which, in turn, water at 360 F will be pumped under pressure to various factories. Each factory will have its own heat exchanger and by circulating the water at this high temperature, low-pressure steam or hot water, as required, may be generated in the individual factory. A low-pressure boiler will be provided to supply steam at 160-lb pressure



Heat flow diagram showing the approximate Btu's required for power generation and the amount passing to process

for supplementing the exhaust steam demand. This boiler will be controlled automatically in accordance with this steam demand.

It is planned further to vary the vacuum on the low-pressure turbine so that circulating water will be available at 97 to 150 F for hot water heating. An underground river at the colliery will provide abundance of circulating water. The scheme promises an overall thermal efficiency of about 60 per cent.

Recommends Subsidizing Research in Coal Processing

In his presidential address before the Institute of Fuel on October 9, Sir John Cadman cites figures showing the greatly increased efficiency in the utilization of coal in England during the past twenty years. The domestic consumption of coal decreased from 189,300,000 tons in 1913 to 161,500,000 tons in 1934 during which period industrial power capacity has trebled. The address,

which is reported in *Engineering* of October 25, stresses the desirability, as a matter of national well-being and security, of extending encouragement to the coal industry through subsidizing research in coal processing. It is the hope that domestic and government needs for fuel oil may thus be rendered independent of importations and at the same time the basic coal industry may be fully sustained.

Air Lift for Ash Sluicing

Employment of the air-lift pump in hydraulic sluicing of ashes is discussed by T. Steen in a recent issue of *Die Wärme* in connection with an installation at Finkenheerd, Germany. This is said to be capable of handling up to nearly a ton of ash and clinker per minute to a height of 51 ft. About 800 gal of water per minute and air at 17-lb gage are employed. Pieces of clinker up to 8-in. diameter are said to be handled easily. The ashes are delivered approximately half a mile distant.

Generating at 33,000 Volts

A 50,000-kw turbine-generating set ordered for the Manchester power station represents a new departure where high voltage is required. It will generate direct at 33,000 volts, at which voltage the current is transmitted over the "grid" instead of stepping up from 6000 to 11,000 and then to 33,000. *Industrial Britain*, November 1935.

Addition of Water to Slack

A paper by A. C. Dunningham and E. S. Grumell published in the October *Journal* of the Institute of Fuel (Great Britain) describes a series of experiments by the authors to determine the effect of adding water to slack coal.

The investigation showed that the addition of water produces a fuel bed of more uniform porosity with a lower resistance to the passage of air and that the resulting improved combustion is attributable to the more uniform air distribution.

The resistance of a full bed of slack under ordinary conditions decreases from a maximum with dry fuel to a minimum when the requisite quantity of water is added. The amount of free water necessary to given minimum resistance depends on the fineness of the fuel and may vary from 5 to 7 per cent for ordinary slacks to as much as 10 per cent for coal containing 50 to 60 per cent fines through $^1/_8$-in. screen. The effect of water on the resistance was found to be independent of the caking properties of the fuel.

While the addition of water reduces the efficiency by approximately 0.1 per cent for each 1 per cent of water added when the exit gas temperature is around 290—300 F, the authors contend that this decrease is offset by the lower draft required, less fines being carried up the stack and smaller loss due to excess air; also that there is less carbon loss to the ashpit.

The water has a tendency to slow down the rate of ignition through the fuel bed; hence it may be necessary to carry a thinner fire. It is most important, however, that the wetting down be uniform and it is recommended that this operation be done some hours before firing the slack coal.

German High-Pressure Industrial Power Plant

At the Hoechst Works of the I. G. Farbenindustrie A.-G. three Loeffler boilers are installed, operating at 1706 lb per sq in. pressure to cover the base load for requirements for process steam which amounts to from 140,000 to 200,000 lb per hour at 45.5 lb per sq in., leaving the peak requirements of 340,000 lb per hour to be supplied from existing boilers operating at 213-lb pressure. Three back-pressure turbines passing a total of 300,000 lb of steam per hour are used for the stage from 213 to 45.5 lb and a fourth turbine operates between 1706 and 213 lb. Steam is delivered to the high-pressure turbine at 914 F.

Ultimately five high-pressure boilers will be installed. The first three units are fired with traveling grate stokers from double hoppers which have provision for either mixing the fuels or feeding them to the grate on the sandwich system. A Ljungstrom air preheater delivers air at a temperature of 350 F—*The Fuel Economist*, October 1935.

REVIEW OF NEW BOOKS

Any of the books reviewed on this page may be secured from Combustion Publishing Company, Inc., 200 Madison Ave., New York

Reducing Industrial Power Costs

By David Moffat Myers

As the title implies, this book deals with the generation and utilization of steam and power from the economic angle rather than from that of design. It is not written for technically trained power engineers but rather for executives and managers, with or without some engineering background, who have supervisory power responsibilities and may at times be faced with the necessity of making decisions in such matters. Hence, the text is essentially non-technical and of an educational or informative character.

Chapters on the selection of fuel, making or buying power, control of efficiency, steam plant losses and savings, the human factor, etc. are typical of the economic treatment. Other chapters on the boiler plant, steam pressures, fuel burning equipment, prime movers, boiler water treatment, heating systems, etc., serve to give the reader a rather general idea of practice, although it is unfortunate that more illustrations were not employed to differentiate between basic equipment types.

The "Power-Loss Chart" provides a most convenient method of checking and correcting losses that may be going on in an industrial power plant, and a concluding chapter on "Power Facts and Data" provides a useful reference for comparison.

The book contains 378 pages, 6 × 9, bound in cloth. Price $4.00.

Boiler Water Troubles and Treatments

By R. E. Summers

This 52-page bulletin is published by the Engineering Experiment Station of the Oregon State Agricultural College, Corvallis, Oregon, and although dealing in general with boiler ills and their causes and descriptions of the various treatments used, it lays special stress on the feedwater problems encountered in western Oregon. Engineers having to do with boiler operation will find much that is informative in the bulletin. Its price to others than residents of Oregon is twenty-five cents.

Handbook of Chemistry and Physics

(Twentieth Edition)

The new edition of this well-known handbook, which has just been published, contains many new and revised features, among the most important of which are the following:

The Table of Physical Constants of Organic Compounds, occupying some 200 pages, has been greatly enlarged in scope and changed in form. Recognizing the importance of uniform and correct nomenclature, cooperation of Dr. Austin M. Patterson of Antioch College, member for the United States of the Committee on Organic Nomenclature of the International Union of Chemistry, was secured. Dr. Patterson has had full charge of the naming and the arrangement of the Organic Compounds and has included a large number of cross references to make this table easier to use.

The Formula Index of Organic Compounds, comprising about 30 pages, has been added in response to numerous requests. In it Organic Compounds are listed according to their empirical formulas and refer by number to the compounds given in the Table of Physical Constants of Organic Compounds.

Great diversity exists in the pronunciation of chemical names. In the interest of uniformity the 20th Edition contains the general rules and list of words with their recommended pronunciations, as reported by the Committee on Nomenclature, Spelling and Pronunciation of the American Chemical Society.

Rules for Naming Organic Compounds: This is a slightly abridged form of the Definitive Report accepted by the International Union of Chemistry.

The *Handbook of Chemistry and Physics* contains 1966 pages, size $4^1/_4 \times 6^3/_4$. Price $6.00.

Coal through the Ages

By Howard N. Eavenson

This little volume is a compilation of addresses made by the author during presidential visits to various local sections of the A.I.M.E. during 1934 and is published for the Seeley W. Mudd Fund by the society. The text traces in a most fascinating manner the relation of mineral fuels to advances in civilization; it describes the early mining methods and their subsequent development, and discusses coal as a pertinent factor in our national economy. Well executed pen sketches add to the attractiveness of the book, which covers 123 pages, $5^1/_2 \times 8^1/_4$, bound in cloth. Price $1.50.

Fans

By Theodore Baumeister, Jr.

The author, who for several years has conducted a course in air and gas machinery at Columbia University, has prepared this book not only as a reference in teaching but also as a practical treatise for those who from time to time may be called upon to select fans for specific purposes.

For this reason the text has been arranged logically by first describing the principal types and commercial makes of fans and blowers; then discussing the characteristics of these types, in which connection terms and laws are explained; and then a chapter on selection, which includes numerous tables. "Theory and Design," "Fluid Flow" and "Fan Testing" are the titles of subsequent chapters for those who may have occasion to go into this phase of the subject.

The book contains 241 pages, 6 × 9, bound in cloth. Price $3.50.

EQUIPMENT SALES

Boiler, Stoker, Pulverized Fuel

As reported by equipment manufacturers of the Department of Commerce, Bureau of the Census

Boiler Sales

Orders for 111 water-tube and h.r.t. boilers were placed in October

	Number	Square Feet
October, 1935	111	472,016
October 1934	64	161,860
January to October (inclusive, 1935)	848	2,830,088
Same period, 1934	747	2,168,902

NEW ORDERS, BY KIND, PLACED IN OCTOBER 1934–1935

Kind	October 1935		October 1934	
	Number	Square Feet	Number	Square Feet
Stationary:				
Water tube	84	438,856	37	133,141
Horizontal return tubular	27	33,160	27	28,719
	111	472,016	64	161,860

Mechanical Stoker Sales

Orders for 310 stokers, Class 4* totaling 51,031 hp were reported in September by 68 manufacturers

	Installed under			
	Fire-tube Boilers		Water-tube Boilers	
	No.	Horsepower	No.	Horsepower
October 1935	275	36,071	35	14,960
October 1934	248	27,582	44	19,041
January to October (inclusive, 1935)	1,425	186,085	479	180,116
Same period, 1934	1,337	167,100	421	165,079

* Capacity over 300 lb of coal per hr.

Pulverized Fuel Equipment Sales

Orders for 25 pulverizers with a total capacity of 203,480 lb per hr were placed in October

STORAGE SYSTEM

	Pulverizers				Water-tube Boilers		
	Total number	No. for new boilers, furnaces and kilns	No. for existing boilers	Total capacity lb coal per hour for contract	Number	Total sq ft steam-generating surface	Total lb steam per hour equivalent
October 1935	..	..	..	....	..	....	......
October 1934	..	..	..	....	..	....	......
January to October (inclusive, 1935)	..	..	..	....	..	....	......
Same period, 1934	2	1	1	46,000	*	*	*

DIRECT FIRED OR UNIT SYSTEM

	Pulverizers				Water-tube Boilers		
October 1935	24	24	..	202,480	16	200,507	1,755,500
October 1934	7	5	2	24,870	7	33,094	211,750
January to October (inclusive, 1935)	110	75	35	673,790	88	621,184	5,814,660
Same period, 1934	79	57	22	496,450	62	400,497	4,104,570
					Fire-tube Boilers		
October 1935	1	..	1	1,000	1	1,500	10,000
October 1934	...	..	..	.....	..	.....	......
January to October (inclusive, 1935)	5	..	5	5,300	5	9,380	52,500
Same period, 1934	10	3	7	10,230	11	12,486	96,300

* Data not available.

Film Strength of a Lubricant

A bulletin just issued by the Industrial Lubrication Council, defines "film strength" (which is interchangeable with oiliness, adhesion, greasiness and load-carrying power) as the resistance to rupture of any part of the films of lubricant covering the metal surfaces of a bearing. Under heavy or shock loads, if such bearing surfaces are damaged by direct metal-to-metal contact, the cause is said to be the poor "film strength" of the lubricant as designating its unsatisfactory load-carrying properties.

When machinery is forced to maximum speed and made to carry greater loads than it is designed normally to handle, then the bearings overheat unduly, thinning the lubricant and reducing its power of adherence to the metal surfaces. In this weakened condition, extra shocks or foreign matter such as dirt or sludge will cause the films to break, allowing the opposing metal surfaces to strike, bringing on instantaneous higher local heats which prevent the films at that point from immediately reforming. This is the critical point in all machine lubrication, for then, if immediate conditions of lubricant, load, speed, cleanliness and cooling do not favor the situation, the phenomenon of bearing failure takes place.

As compared to all mineral oils of the same consistency, oils made from animals and vegetables, when new, have a greater degree of film strength, and this property increases as these oils become rancid through decomposition by age or through continuous re-use. Then the fatty acid content increases to a point that will cause these oils to be unsatisfactory in all modern continuous circulating systems, as the fatty acids will then solidify and form sticky and non-lubricating films and substances. In their natural state the fatty acids which give this quality, referred to at times as "greasiness," can be removed from the original oils and then compounded with the mineral oils, resulting in an increase of their property of adhesion to metal somewhat in proportion to the amount of fatty acids used. Mineral oils, as such, all vary considerably in this property of adhesiveness or film strength. There is a definite technique established for artificially giving to the mineral lubricants various increasing degrees of load-sustaining properties. But this has not been reduced to a system of measurement of mechanical effect, nor has any agreement been reached regarding the proper name to be used describing this condition.

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